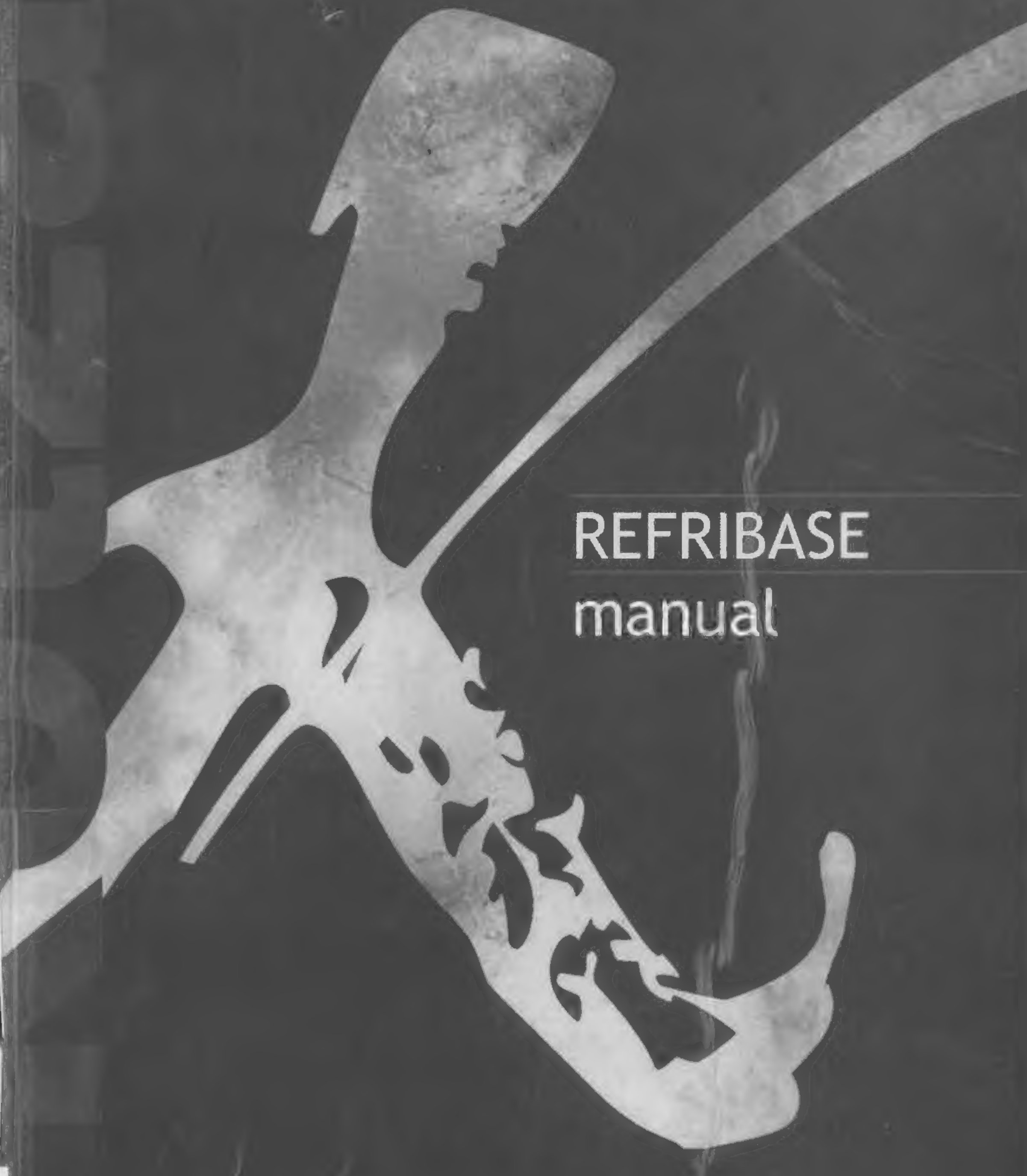
# THE PRACTICAL REFRIGERATION AND AIR CONDITIONING MANUAL FOR BEGINNERS



# REFRIBASE

## manual

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# INTRODUCTION

There are many books available that deal with the thermodynamics of refrigeration systems and which explain the operation and technology of these systems in great detail.

*If you have difficulty in getting the most out of those types of book, then Frigobase has been specially designed for you*

In the same way, if you find a lot of the information used in manufacturers' technical literature difficult to understand, *then once again Frigobase can help you.*

*Don't worry,* we won't be spending all our time studying physics, doing complicated calculations or anything of that sort. We'll just be observing things that happen around us and making use of those phenomena of physics that are part of our daily lives. We'll look at things like the way water boils, pressure-cookers, bicycle pumps, condensation on glass, sponges etc.

The objective of the first part of Refribase is to examine the refrigeration system of a refrigerator. This will help you appreciate and understand its' operation. As you will almost certainly own a fridge, you can easily examine it, touch it, and locate its various components. We'll then be able to examine how air conditioning systems work, so that we'll be able to install, maintain and repair them.

If you already have a good understanding of refrigeration systems used in domestic A/C, Frigobase might at times appear to be too simple for you. If this is the case, read quickly through the parts involved. Even then, at the end you'll find that you will have learned a few things!

***Above all, bear in mind that the manual that you're reading at this moment is only a very small part of a complete method of learning about refrigeration as it's applied to air conditioning. That's why we strongly recommend using the REFRIBASE software in conjunction with the study of this manual, to give yourself the best chance of becoming a real expert.***

**Translated from French by Gareth J.Rees**

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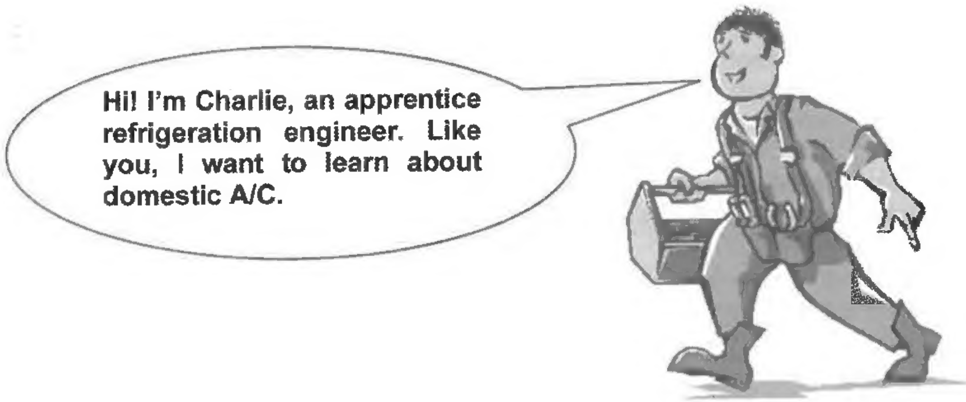
You'll be accompanied by two characters in the first part of your training: a refrigeration apprentice, and a qualified engineer...





So now, over to you! Above all *don't go too quickly*, and take plenty of time to think things over. Don't hesitate to re-read a chapter if some things seem difficult to understand: *you'll find it's worth it!*

***Good luck with your studies. You'll see that it isn't as difficult as all that to master domestic A/C if you really want to...***

**Throughout this manual any reference made to the gender of individuals or groups have all been masculine. This has been done solely in the interests of simplicity and clarity, and is in not intended to be exclusive in any way whatsoever. The objective of this work is to assist ALL individuals in improving their proficiency in refrigeration and A/C repairs, regardless of gender, race or religion.**

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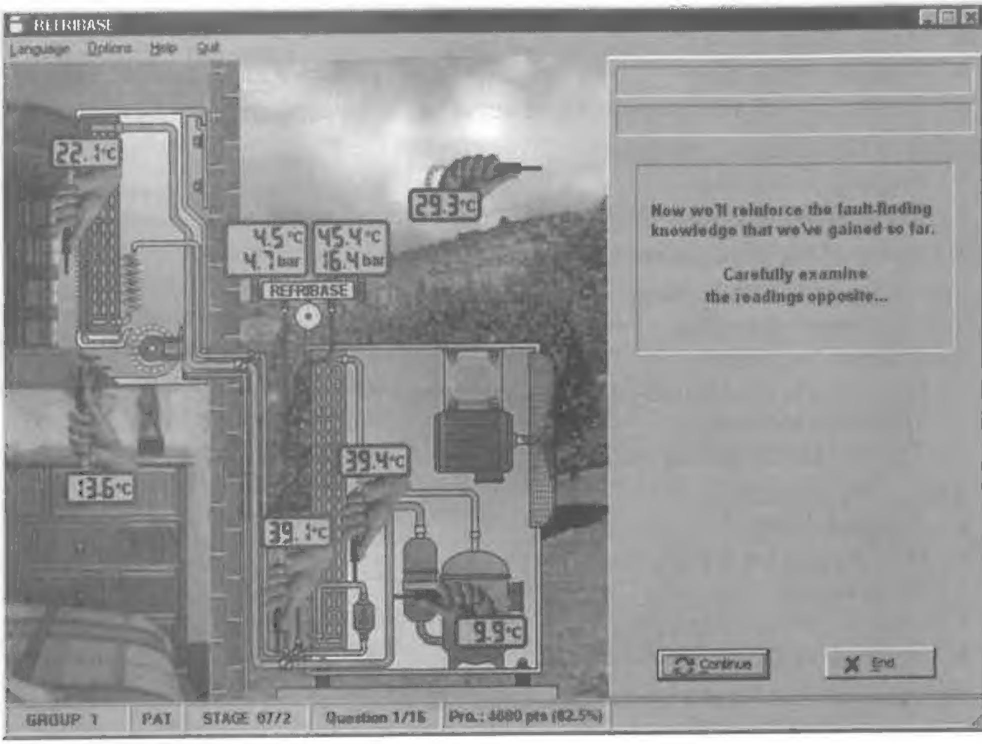
# REFRIBASE SOFTWARE FOR YOUR PC




REFRIBASE is a study method that is made up of this 266-page manual plus a graphics program on CD-ROM for Windows /98/Me/NT/2000/XP.

*Together they allow a novice to acquire the necessary knowledge to effectively maintain and repair stand- alone A/C systems.*

REFRIBASE is a self-adapting program, which poses practical problems that change according to the quality of the previous responses. In this way, every time the program is used, the situations presented will be different.

You respond to each problem by simply clicking your mouse. Immediately, REFRIBASE gives you an updated proficiency coefficient and displays a situation sensitive corrected answer on the screen.

*REFRIBASE allows you to interrupt the current session at any time. At the start of the next session it takes you to the exact place in the program where you left off.*

The increasing levels of difficulty, in conjunction with the wide diversity of the situations presented means that fast and accurate diagnostic skills are acquired.

**Real-time auto-correction allows a student to progress entirely unaided, ensuring that progress is as rapid as it is spectacular.**

In addition, an integral 'manager', accessible by means of a password, analyses the results obtained by each user at every step.

**Thanks to its animated graphics, its great simplicity of use, its interactive and progressive learning approach and its auto- adaptive capabilities, REFRIBASE truly is an ideal tool to use for becoming an expert in stand-alone A/C**

*Remember, if you don't make use of the manual + software together, it'll be like trying to appreciate a piece of music just by reading the score!*

E-mail: **kotza@kotza.com** Website: **www.kotza.com**

# THE REFRIGERATOR: AN INTRODUCTION

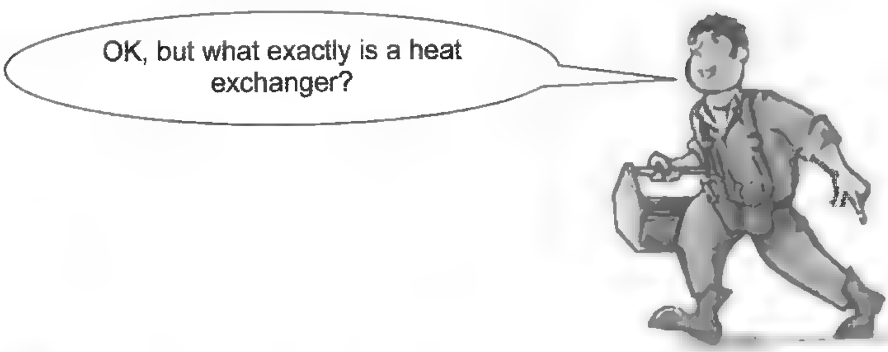
## 1. The function of the refrigerator:

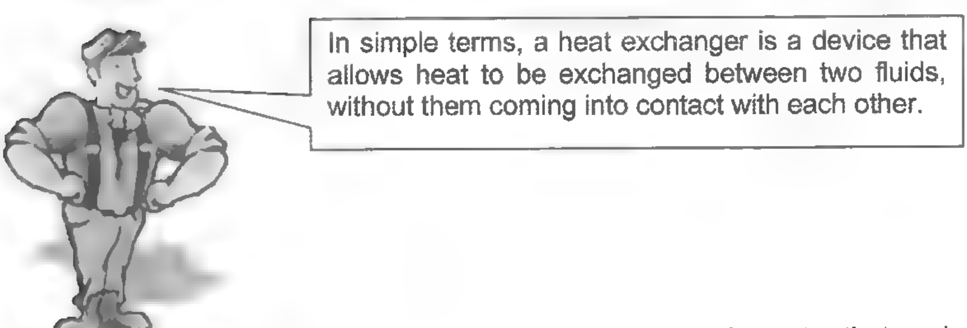
The refrigerator's role is to maintain the foodstuff that it contains at a temperature low enough to slow down the growth of bacteria, and so increase the length of time that food can be stored.

To do this, we will see that the refrigerator, *in contrast to what many people think*, does not produce cold, but rather it removes, or pumps away, heat!

In effect, it pumps heat from the interior of the fridge and discharges it to the exterior. In order to do this, a fridge is equipped with two heat exchangers: one to absorb heat, and the other to discharge it.

## 2. Finding the heat exchangers:

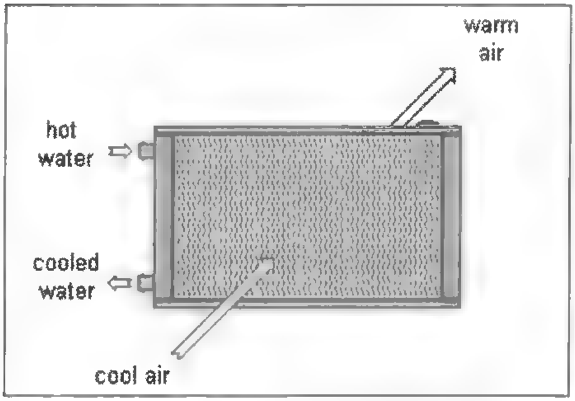



In your car, there is a radiator to keep the water that cools the engine at a reasonable temperature. The radiator is nothing but a heat exchanger.

*By the way, do you understand how the radiator works?*

In actual fact, the radiator of your car is a heat exchanger.



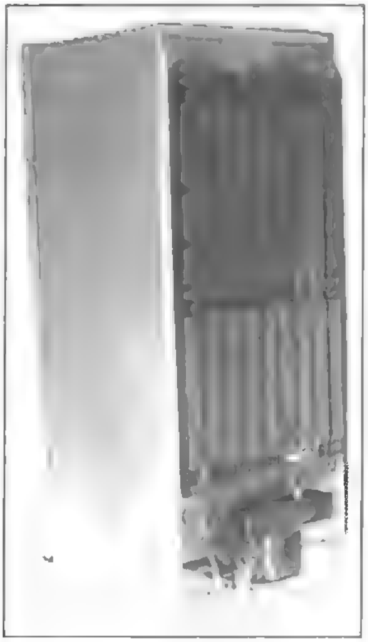

It enables an exchange of heat between the hot water circulating ***inside*** the radiator and the cooler air circulating ***outside***.

*The water and air are not in direct contact, unless, of course, your radiator has been holed !*

The exchange of heat between the hot water arriving from the engine and the cooler air outside removes heat from the water (and therefore cools it). At the same time, the outside air is warmed as it absorbs the heat lost by the water (this hot air is used to heat the car's interior in winter).

In a refrigerator, the same principle applies. It allows an exchange of heat between the air and a special fluid (called the refrigerant). But, let's take things slowly; we'll explain heat exchanges more fully as you progress.

Now, over to you! Take charge of the investigation yourself and have a close look at your own fridge, on the inside as well as outside.



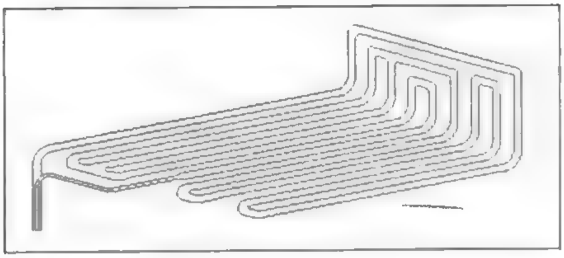
Take care! Some parts of the system can be very hot *(don't burn yourself)* and there is electrical equipment present (*avoid electrocuting yourself*). Simply try to discover where heat exchanges take place.

I expect that you already know where the 'cold' heat exchanger is found (it's generally where ice cubes sit waiting for their gin and tonic!). Now, find the 'hot' heat exchanger.

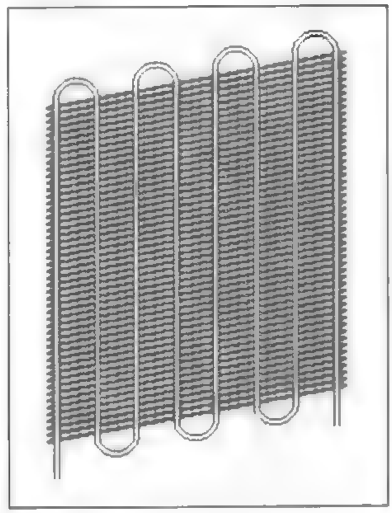
That's correct. The 'hot' heat exchanger is where you find the ice compartment. As for the 'cold' heat exchanger, it's that black grill situated behind the fridge.

*I can see you looking puzzled. Don't you agree?*

Of course you don't and you're absolutely correct; it's quite the reverse ! The ice compartment is cold, and the black grill behind the fridge is hot. Now you know where the two heat exchangers are found.



The 'cold' heat exchanger represented alongside is found inside the fridge. Sometimes our American friends call it the "freezer".



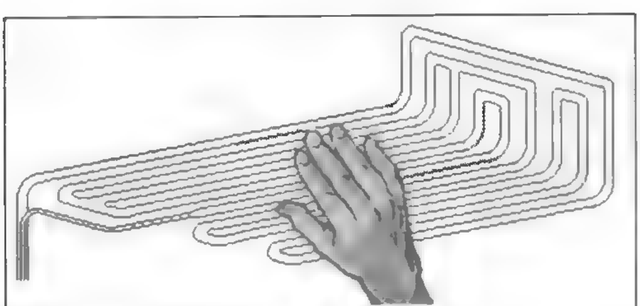
The 'hot' heat exchanger is a kind of grill (often black) found externally at the back of the fridge. If the fridge is working, and you pass your hand over this grill, you'll sense heat.

Soon, you'll understand exactly what goes on inside these heat exchangers, but first we must clarify a few basic ideas.

## 3. What is heat?

Heat is a sensation that you experience, for example, when you touch an object whose temperature is different from that of your hand. Something might feel, for example, freezing cold, very cold, cold, cool, warm, hot, very hot, boiling hot...etc.

What is actually happening is that your brain is making a comparison between the level of heat in your body (your temperature) and the object with which you are in contact.

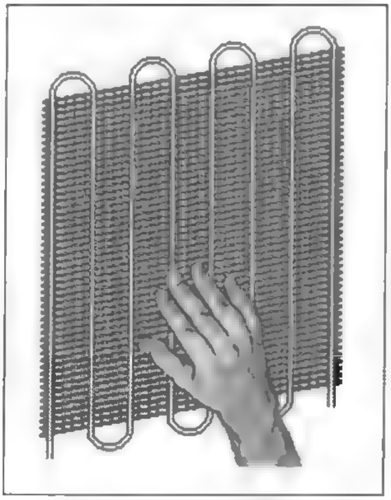


In the example opposite, Charlie's brain is comparing the temperature of the fridge's 'cold' heat exchanger with the temperature of his hand.

Note that the palm of your hand is generally at a temperature somewhere between 30 and 33°C (unless you have a fever!).

Charlie is trying to find out if the heat exchangers are hotter or colder than his hand. *All he's doing is making a comparison.*

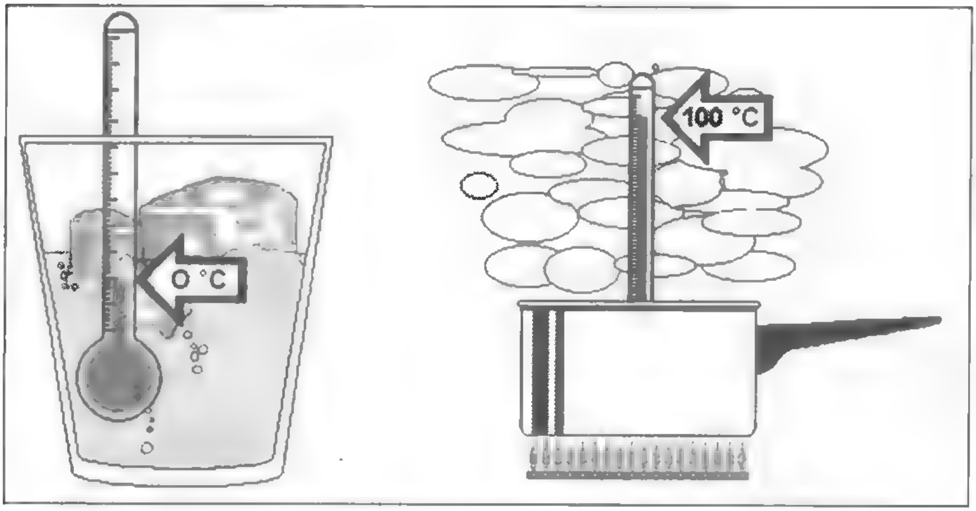
You'll see immediately that this technique of estimating temperature is quite imprecise and a bit haphazard.



The greater the temperature difference between the palm of your hand and the thing you're trying to measure, then the harder it is to estimate its temperature, and the greater the risk of error.

For example, you must avoid getting burnt (how do you estimate the temperature of hot oil in a deep fat fryer by touch?), and what do you do to measure the temperature of hazardous materials (an acid, for example)? It's for this sort of reason we use a thermometer.

We generally hear people speak about degrees Celsius (°C) for measuring temperatures (for example, when we watch the TV weather forecast).




On the °C scale, zero (0°C) corresponds to the temperature shown on a thermometer immersed in melting ice. 100°C corresponds to the temperature of boiling water.

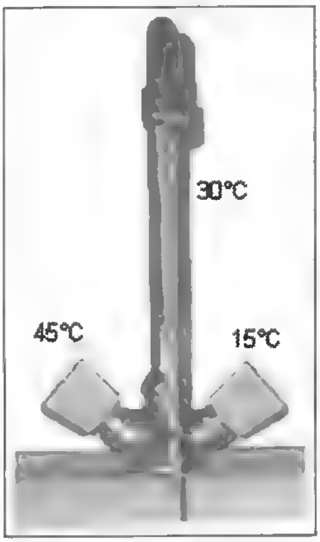
As these two points are separated by a hundred (hence the 'cent') divisions (from 0°C to 100°C), degrees Celsius are sometimes also known as degrees Centigrade: it's exactly the same thing.

Let's continue then. The thermometer is a measuring instrument that tells us *precisely* the amount of heat in a body.

In fact, then, a thermometer gives you a precise measurement of the level of heat in a body, a bit like a petrol gauge tells you the amount of petrol in your car's fuel tank.

## 4. Transfer of heat:

In everyday life, we often need to heat objects or cool objects.




Take, for example, a mixer tap like the one shown opposite. In order to obtain a comfortable water temperature, we mix hot water with cold water.

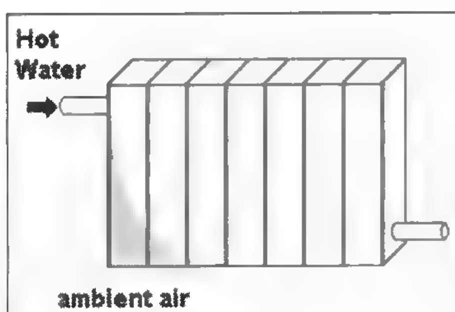
We cause an exchange of heat between the hot water at, say, 45°C, and the cold water at 15°C to produce water at 30°C: there has been what is called a thermal exchange.

In our example we have two things with the same properties that mix and exchange heat.

However, thermal exchanges are not just limited to similar materials, and things that exchange heat don't necessarily have to mix.

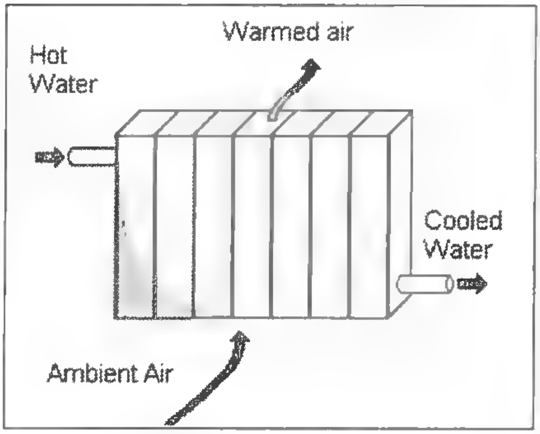
For example, in order to heat a room, we can use a central heating radiator, inside which hot water is flowing.

This heat exchanger allows a transfer of heat between the water in the heating system and the ambient air in the room.




*What do you think: does the water heat up the air or vice versa?*

It's easy to show that the hot water gets cooler as it passes through the radiator, whilst the air becomes warmer.




This can be verified simply by touching the hot water inlet pipe at the top of the radiator, and then the water outlet pipe.

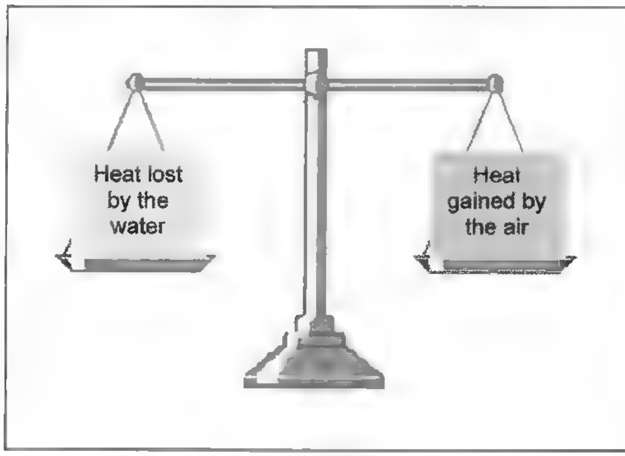
As the air is warmed it rises (This is shown by the dark streaks that are sometimes seen behind a radiator).

From our earlier observations, we can deduce that when two bodies at different temperatures are in contact, then an exchange of heat occurs, which is referred to as a thermal exchange.

During this exchange, heat always passes from the hotter body to the colder one, and so all the heat lost by the water is gained by the air.

The scales opposite should help us remember that:

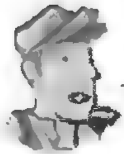
***The amount of heat gained by the air is exactly equal to that lost by the water.***




In the case of the radiator, in order to avoid causing floods, it's easy to see why the water and air can't be in direct contact. The heat exchange is made by means of the radiator as a heat exchanger.

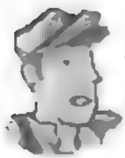
As it passes through the radiator, the water loses heat. Its temperature falls, say, from 80°C to 60°C, but all the heat lost by the water is gained by the air. This is why the temperature of the air increases across the radiator. *No heat disappears, no heat is created: only an exchange of heat takes place.*

**In a heat exchanger, the amount of heat *gained* by the colder body is exactly equal to that *lost* by the hotter body.**



In effect, then, a heat exchanger allows heat to transfer from a hot body to a cold body.

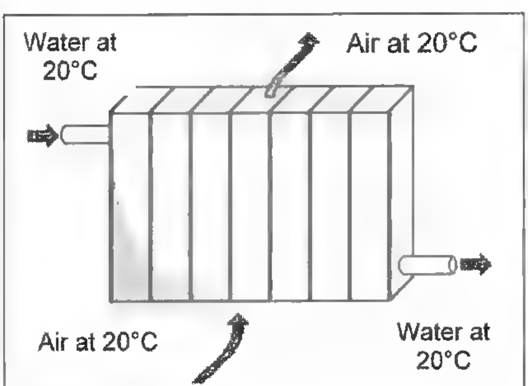
OK, but does the cold body cool the hot one, or vice versa?



Remember this essential rule: heat always flows from the hotter body to the colder body.

And yes, in contrast to what happens in the financial industry, in physics, the rich always give to the poor! *Heat always passes from the hot to the cold.*

In the example below, water arrives at 20°C but the ambient air temperature is also 20°C. We can see that that since there is no difference in temperature between the air and the water, an exchange of heat is impossible.

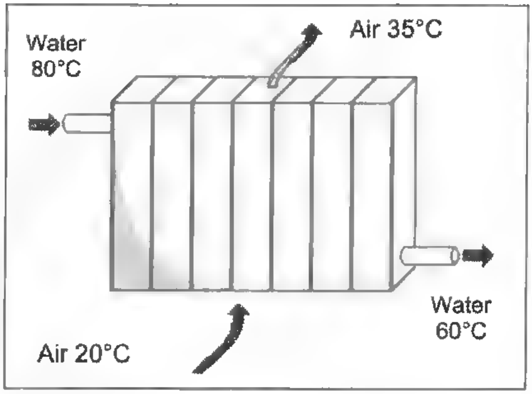



**There can only be an exchange of heat between two bodies if those two bodies are at *different* temperatures.**

In this new example, the two fluids (water and air) are at different temperatures.

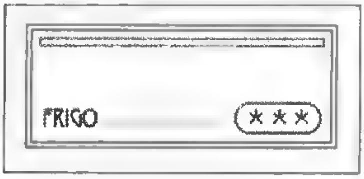
In this situation, heat exchange can occur.

**Heat always flows from the hotter body to the colder body.**

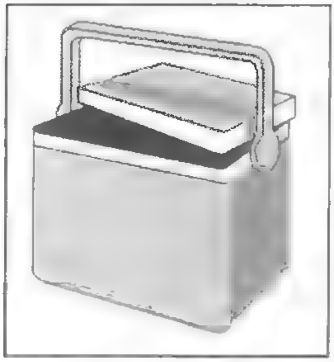



Of course, these fundamental rules also apply to your refrigerator. The 'cold' heat exchanger should be at a lower temperature than your food, otherwise no heat exchange will be possible, and the food won't be chilled.

For your information, the temperature that the 'cold' heat exchanger should maintain in a refrigerator is:

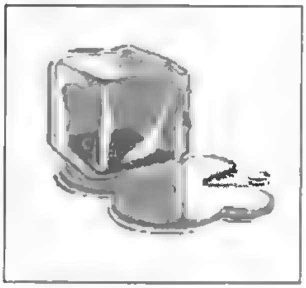



- -6°C for a one-star freezer *
- -12°C for a two-star freezer **
- -18°C for a three star freezer ***



In conclusion then, in order to chill food, all you need to do is place it somewhere where the temperature is lower than its own (for example inside a cool box).

The food will then be cooled as it gives up heat to the ice.



However, there is a problem. As it absorbs the heat given out by the food, the ice will warm up and melt.

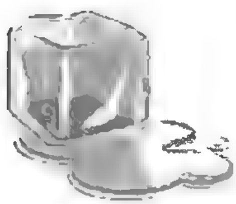
After a time, the ice will obviously all be melted, and won't be able to absorb any more heat...

When all the ice has melted, our food won't be cooled any further. We must then put more ice in the coolbox. This seems straightforward, but where will we find more ice?

Either we get our ice from a glacier (not all that easy if you don't live high up in the mountains), or we take some ice from a deep freeze. A freezer, of course, uses the same operating principles of operation as a fridge, but how does it work?

Gradually you will get all the pieces of information needed to answer this question. You will then be able to understand the operation of air conditioning so that you can install and commission A/C, and diagnose common A/C faults. This is the aim of this course.

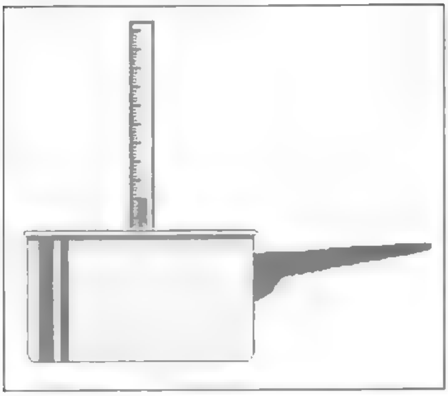
Up until now, this first part may seem easy. *Nevertheless, make sure that you have understood everything before you continue…*



# THE PHENOMENON OF BOILING

To understand the operation of our refrigerator, we will have to refresh our memories, or perhaps even improve our understanding a little. In order to do this we'll look at what's happening all around us.

## 1. Experiments :

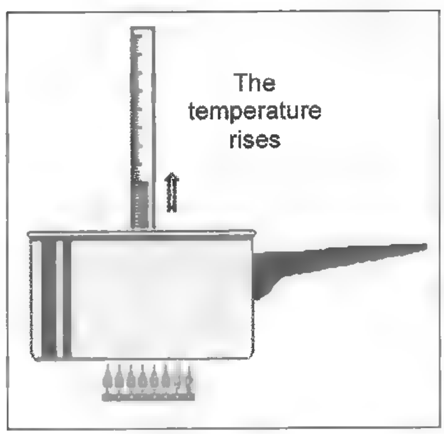


Let's start by looking at a simple experiment with a saucepan of water. Take a saucepan, fill it with water from the tap and then place it on a gas stove or burner.

To get the best results from our experiments, we also need a thermometer (graduated to at least 100°C) in order to measure the temperature of the water.

Now, light the flame of the stove. *What do you notice?*

As the thermometer shows, the presence of the flame causes a rise in the temperature of the water.



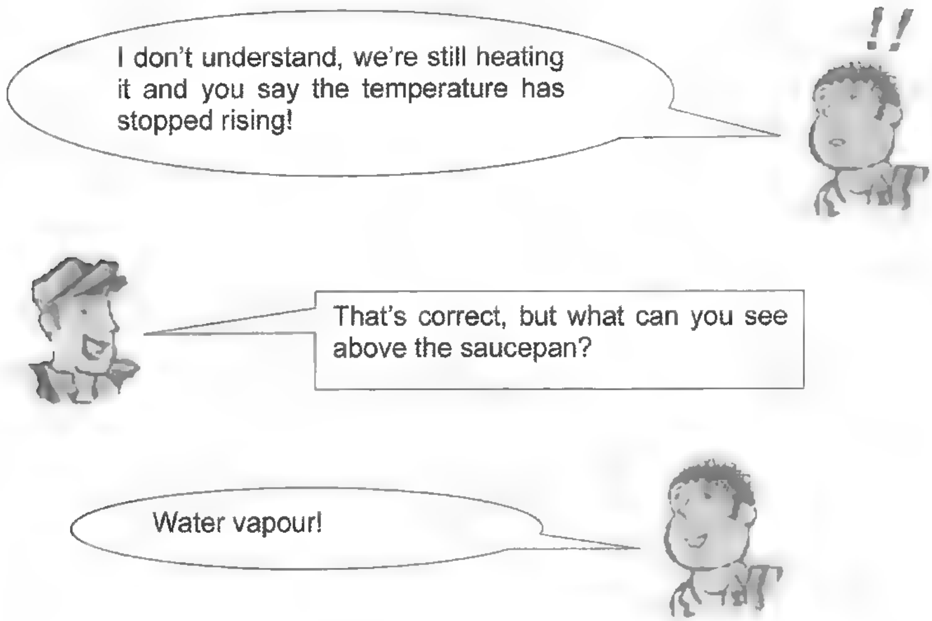

If you extinguish the flame, the temperature of the water stops rising. If you wait a while, it even starts to fall.

These observations are quite easily explained: when the flame is lit, it supplies heat to the water, whose temperature then rises. Then, as soon as you turn off the burner, as the water is hotter than the surrounding air, it gives up heat to the surroundings (that's why the water temperature falls).

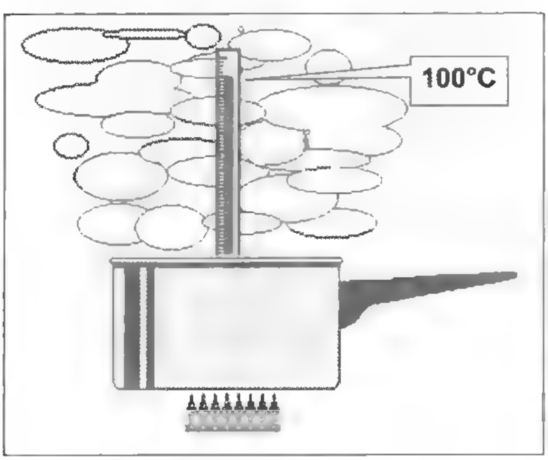
Now, if you turn the burner back on, the temperature of the water starts to rise again. But let's see if we leave the burner on, what will happen to the temperature of the water? Will it rise indefinitely?

*Try and answer this before you continue…*

You will perhaps remember your physics lessons from long ago: *once it gets to 100°C, the temperature of water stabilises, and will increase no further, although the burner is still supplying heat.*




What you will notice is a lot of steam being given off above the saucepan. Also, you can see that the water level in the pan is getting lower and lower. *What is actually happening*?




We are observing a very important phenomenon of physics, called:

***A change of state.***

During this change of state, water changes from a liquid state to a gaseous state (steam).

In fact, it is easy to see that the level of liquid falls in the saucepan whilst water vapour is given off: ***the water vaporises.***

In addition, the temperature indicated on the thermometer stabilises at 100°C. Although the burner continues to supply heat, the temperature does not increase further....

So why do you think the water temperature has stopped increasing?

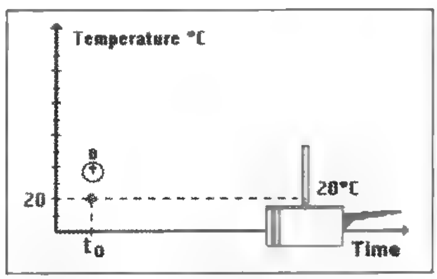
One thing's certain: the heat supplied by the burner isn't causing the water temperature to rise any more. Also, you can see that the liquid water is turning into steam. From this, then we can say that the heat from the burner is no longer making the water temperature rise, but it is causing a change of physical state.

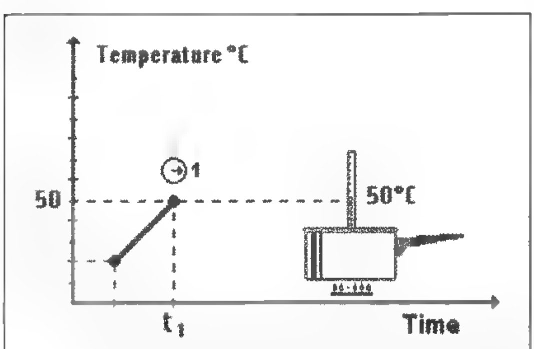
Charlie is right, but in order to have a better understanding of what's happening, lets repeat the experiment together, this time with the aid of a graph.

## 2. Investigation:

Let's refill the saucepan with water whose temperature is, say, 20°C. Since the burner is off, there is no heat supply, and the water remains then at 20°C.

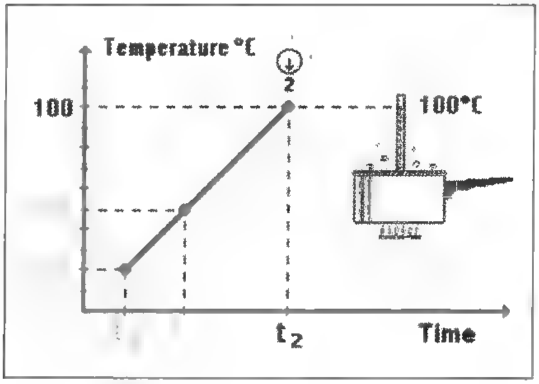
We start the experiment *at time $t_0$* by lighting the burner, and mark this point on the graph (at time $t_0$ the temperature is 20°C).




We observe that the temperature of the water in the pan steadily increases: there is a transfer of heat from the flame to the water.

For example, *at time $t_1$*, the temperature of the water has risen to 50°C. The surface of the water remains flat and quite still.



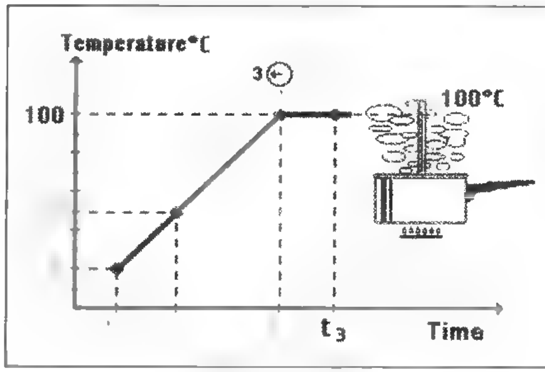

For a further period of time the temperature of the water continues to increase steadily. This is normal, because since the flame is still lit, it is still continuously supplying heat to the water.

Gradually, as the temperature approaches 100°C, we observe that the surface of the water starts to ripple more and more.

When the thermometer reaches 100°C, the water starts to boil and produces large bubbles. We are now at *time* $t_2$, and we can note this point on the graph.

As the burner remains lit, it continues to provide heat to the water. On the other hand, the temperature of the boiling water remains stable at 100°C.

*At time* $t_3$, the water is still at 100°C and large amounts of steam continue to escape from the pan (this is why the level of liquid is falling noticeably).

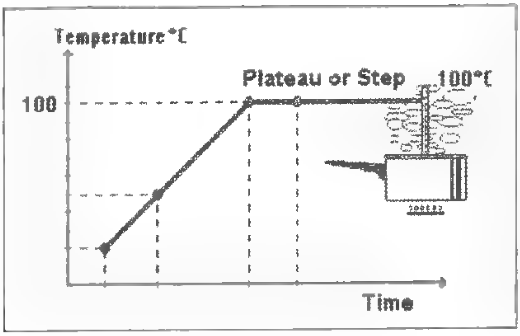



On the graph, there appears to be a horizontal 'step' starting at $t_2$ where the temperature remains at a constant 100°C.

***The heat*** that the burner continues to supply from $t_2$ onwards does not cause any increase at all in the temperature of the water (which remains constant at 100°C), but this heat transforms ***liquid water into water vapour.*** This is what is known as vaporisation.

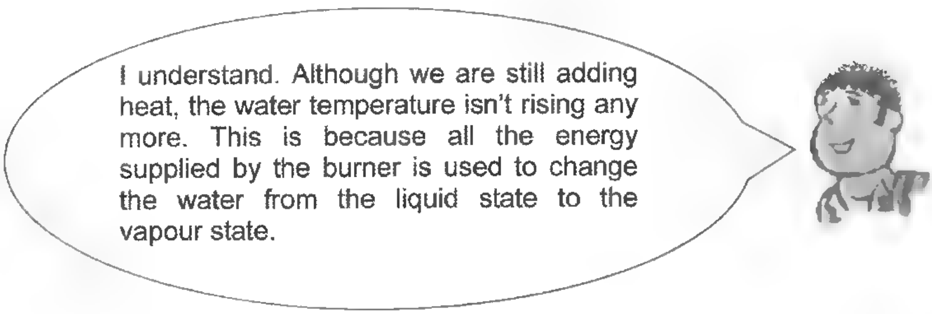
**The change from the Liquid State to the Vapour State is called vaporisation.**

**When a liquid evaporates, it absorbs heat, but its temperature remains constant. The heat absorbed is called *the Latent Heat of Vaporisation.***

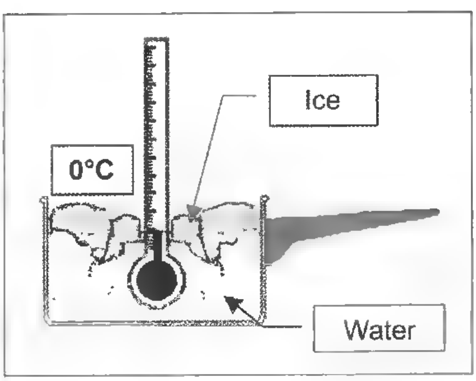



This experiment provides the evidence for us to say that when water passes from the liquid state to the Vapour State, it absorbs heat at a constant vaporisation temperature, making a step in the graph.

The energy absorbed along this step does not increase the temperature at all, but is used *entirely* to cause the change that transforms *liquid* water into *water vapour*.




This phenomenon, characterised by the change of state step, is called the vaporisation or evaporation of water. It corresponds to the transformation of a liquid into a vapour. For water in the open air (that is: at normal atmospheric pressure) the vaporisation step always takes place at 100°C.



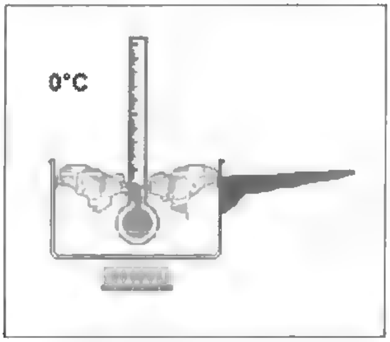

Now, let's perform a second experiment.

Take a saucepan and fill it with ice-cubes and cold water. Wait until the temperature of the mixture is constant, and place a thermometer in the pan.

After a time, the thermometer reads 0°C (this is the temperature of melting ice). At this point, place the pan on the burner on a low flame.

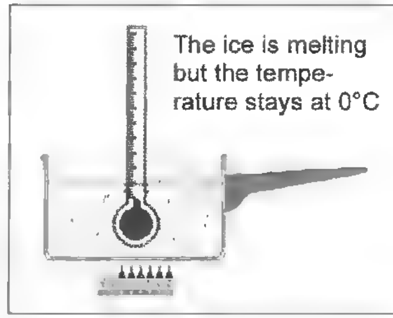
What do you think will happen?

*Try and answer this before going any further…*

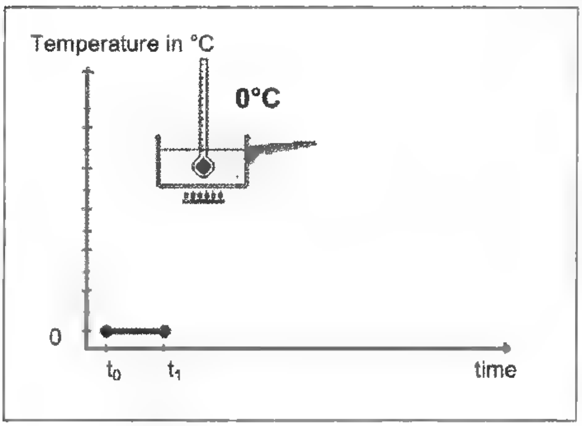



If you can't perform the experiment and draw a graph as we've done previously, it doesn't matter, as this is what we'll see:

Initially, despite the supply of heat from the burner, the temperature of the water remains stable at 0°C.



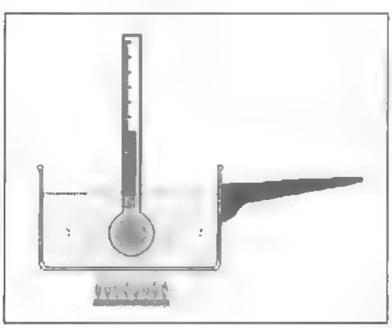

Although the temperature remains constant at 0°C, you'll observe that there is more and more water present, and less and less ice: the ice cubes melt. This phenomenon is called the ***fusion*** of the ice.

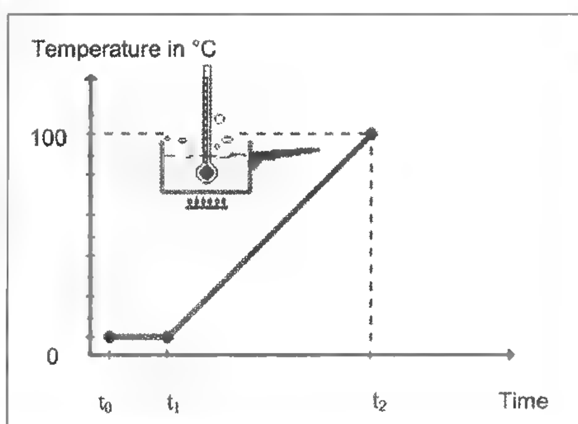



Between $t_0$ and $t_1$, the temperature effectively stays constant at 0°C.

We clearly see that ***a step*** occurs during the melting or fusion of the ice, which corresponds to a change in physical state, i.e. the passage from ***the solid state to the liquid state***. This is called the fusion step.

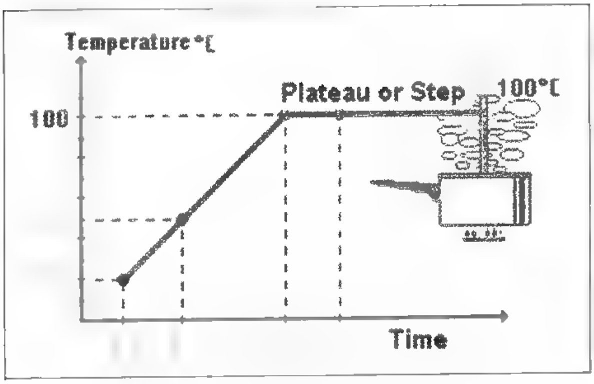
In the second interval of time, *as soon as there are no ice-cubes* left, the temperature of the water starts to rise.






The temperature continues to rise towards 100°C, as we saw previously.

*In this case, what will happen now?*




Of course, once it gets to 100°C, the temperature stabilises once more: this is the beginning of a second step, the one that we have already seen.

This second step corresponds to the change of water from the liquid state to the vapour state: it's our old friend the vaporisation step.

This experiment has allowed us to observe some <u>very important</u> phenomena.

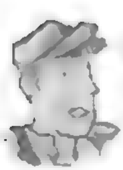
- Water changes from the solid state to the liquid state at a constant temperature (0°C) by absorbing heat.

  **<u>This heat is known as the Latent Heat of Fusion.</u>**

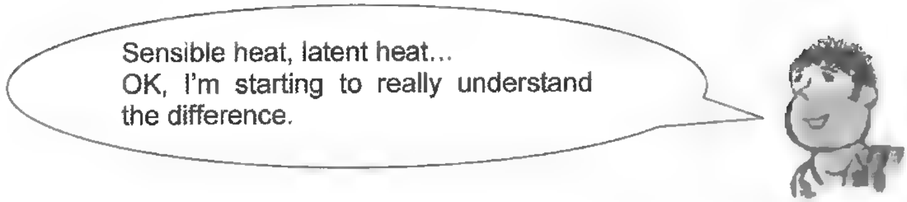
- Water changes from the liquid state to the Vapour State at a constant temperature (100°C) by absorbing heat.

  **<u>This heat is known as the Latent Heat of Vaporisation.</u>**

So, If I've got it right, Latent Heat is the heat needed to cause the change of physical state of a body at a constant temperature.



That's exactly right. When an amount of heat doesn't increase the temperature of a body, but causes a change in its physical state, we talk about ***latent heat***. On the other hand, when the temperature of a body changes (for example when we heat water from 20° to 40°C), we say it's due to ***sensible heat,*** as the temperature change can be *sensed* (detected).




If supplying heat to a body causes an **increase in temperature**, we talk about **Sensible Heat**.

On the other hand, if supplying heat causes **a change in physical state**, the temperature of the body remains constant, and we talk about **Latent Heat.**

## 3. Conclusion:

The two experiments that we have just performed are essential. What they've shown us is that when there is a change of physical state,

- Whether from solid to liquid (*the fusion phenomenon*)
- Or from liquid to vapour (*the vaporisation or evaporation phenomenon*) then the body that changes state always stays at a constant temperature although it is absorbing heat (this is the step phenomenon we have observed).

To understand a refrigeration system, understanding the vaporisation phenomenon is essential, and from now on we must always remember that

To evaporate, water needs energy (heat).

*And more generally:*

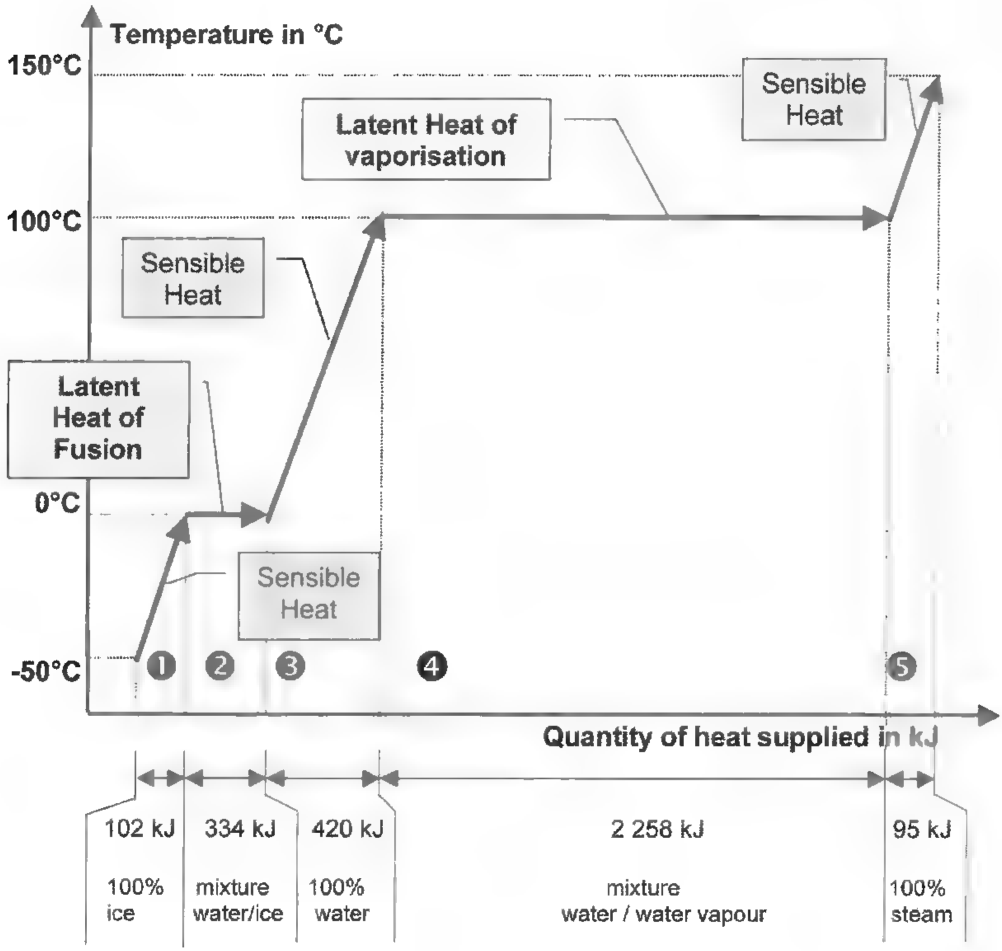
No liquid can evaporate unless it is supplied with energy (in the form of heat).

If, in the ice-cube experiment, you measure:

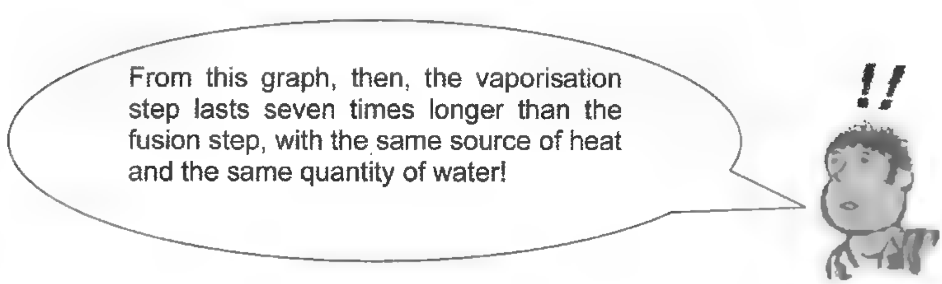
- The time needed to melt all the ice-cubes,
- The time taken to heat the water from 0°C to 100°C,
- The time needed to vaporise all the water in the saucepan.

*You could be surprised by the results…*

In the graph below, we've shown the amounts of heat that you must supply in order to transform 1 kg of ice at –50°C into 1 kg of water vapour at 150°C:




The amounts of heat (energy) are expressed in kiloJoules (kJ) which is the agreed unit of the *système international* (S.I.). These values are only for background: *don't worry* if they don't mean much to you, it's not essential at this stage.



As it evaporates, a liquid absorbs enormous amounts of energy. In our experiment 5.4 times more energy had to be supplied to the liquid to turn it into vapour at a constant temperature of 100°C (phase ❹) than to raise its temperature from 0°C to 100°C (phase ❸). These are the laws of nature, and all we can do is observe them.

In our experiments, I've noticed that every time that the water was in the form of a *mixture* (in ❷ and ❹), the heat supplied was ***latent***.

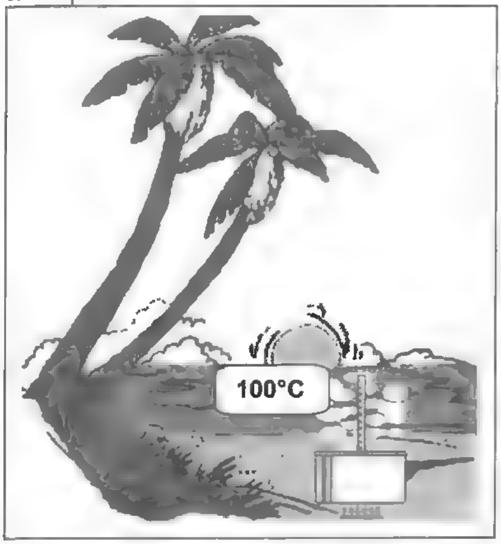
On the other hand, when the water was *completely* in the solid state (in ❶), *completely* liquid (in ❸) or *completely* vapour (in ❺), the heat was ***sensible***. Is that right?

That's quite correct. When the heat supplied to a body causes an increase in its' temperature, we talk about **sensible heat** (we ***sense*** the temperature change)
Whereas, if the heat supplied to a body causes a change in its' physical state, we talk about **latent heat** (we don't sense a temperature change due to the heat supplied: the heat is latent, or ***potentially available***)

We will be discussing these ideas of latent heat and sensible heat again soon. Nevertheless, make sure that that you have understood all this before going any further...

# DOES WATER ALWAYS BOIL AT 100°C ?

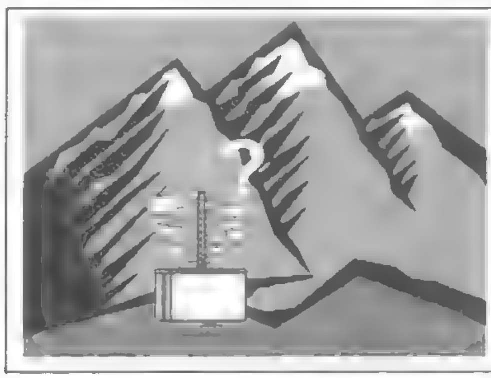
It's true that 100°C is a temperature often associated with boiling water. However, boiling doesn't always necessarily take place at 100°C. Let's take an example.




You've decided to have a meal on the beach, and you're going to prepare hard- boiled eggs. You get your saucepan and your stove in order to boil the water.

You light the stove, and away you go. All you have to do is wait. When the water starts to boil, you place the eggs in the saucepan. Ten minutes later, the eggs are ready, and you turn the stove off. When you eat the eggs, they're cooked. Great!

A few days later, your journey takes you into the mountains. Eager to exercise your expertise in boiling eggs, you get out the saucepan, the stove and your lighter.

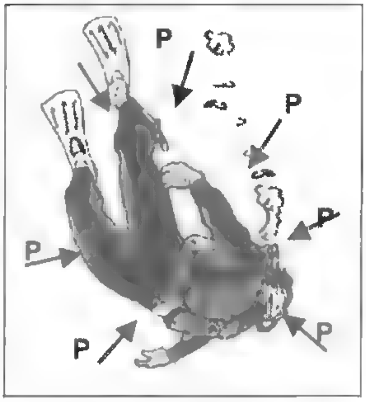


When the water starts to boil, you place the eggs in the pan. Ten minutes later, you turn off the stove. Logically, the eggs should now be ready.

When you actually try the eggs, you discover that the yellows are soft, although you've left them in the boiling water for 10 minutes, *exactly as you had done on the beach!*


*How do you explain this? Do you have any ideas how it happened?*

The problem that you've come across with the eggs is due to a pressure effect that we're now going to try and explain.

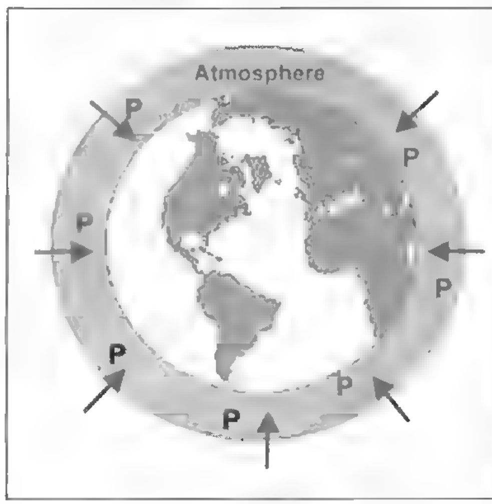



If you have ever done any sub aqua sport, you will be very familiar with the problems of pressure.

What happens is that the deeper a diver descends, the greater the pressure **P** that the water exerts on him becomes. For example, at a depth of 50 metres, the pressure exerted by the water is more than 5 bar (that is, 5 times atmospheric pressure).

This pressure is produced by the weight of the column of water above the diver. This is why the pressure increases with depth.

In the same way, there is a layer of gas around the earth known as the atmosphere. Its thickness can vary, but it is roughly about 20 km thick.




In the same way that the depth of water exerts a pressure on the diver, the depth of the atmosphere exerts a pressure on the surface of the earth.

*As you will perhaps know, this pressure is what we call atmospheric pressure.*

When we are at sea level, the atmospheric pressure is produced by a depth of gas of about 20 km.

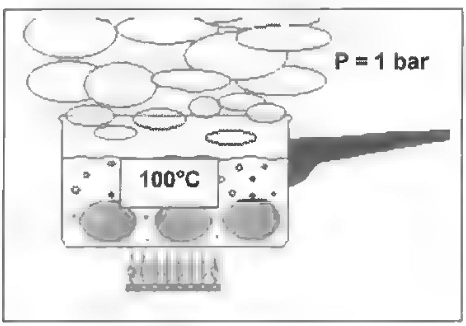
But when we are at an altitude of 3000 m (i.e. 3 km), the depth of the atmosphere is only 20 – 3 = 17 km. The atmospheric pressure is therefore produced by a depth of gas of 17 km (instead of the 20 km at sea level). It's easy to understand, then, why the atmospheric pressure gradually falls as we go to higher altitudes.

For your information, the agreed unit of pressure is the Pascal (Pa). However, in the refrigeration industry, the bar (Bar) is most commonly used. A Bar is essentially the atmospheric pressure that we measure at sea level, that is, at an altitude of 0 metre (we often say that 1 bar = 1 atmosphere).

So, the higher you go in altitude, the lower the atmospheric pressure gets?

That's right. Atmospheric pressure is actually 1.013 bar at sea level, but it's only 0.7 bar at 3000 metres and 0.4 bar at 7000 metres.

But I don't really see the connection between atmospheric pressure and eggs that don't cook properly in the mountains.

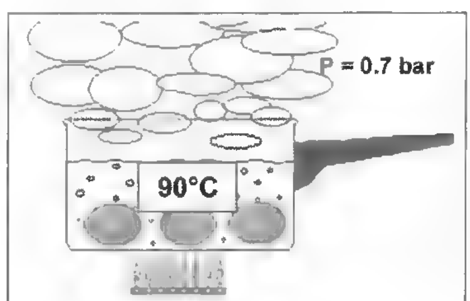



Let's try to solve Charlie's problem. At sea level, that is, at an altitude of 0 metres, atmospheric pressure is 1.013 bar, and water boils quite normally at 100°C.

At this temperature, eggs that have been in boiling water for ten minutes are perfectly hard-boiled.

At an altitude of 3000 metres, the thickness of the atmosphere is less, and atmospheric pressure is only 0.7 bar.

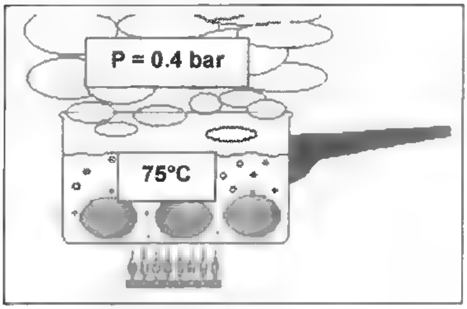
In this instance we see that when it starts boiling, water has a temperature of only 90°C (instead of the 100°C above).




*Before we continue, do you have any ideas about an answer to Charlie's question?*

*Let's see if we can understand it better by exaggerating a little: if the eggs were left in the water for 10 minutes at 20°C, they won't be cooked at all!*

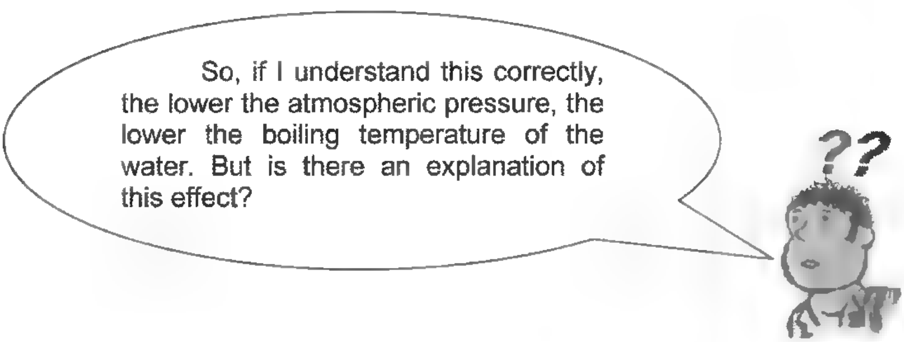
To summarise, then. The colder the water is, the more slowly the eggs cook. If we immerse them for ten minutes in water at 100°C, they cook perfectly. If the water is only at 90°C, it's logical to conclude that the eggs will be less well cooked.




Note that at 7000 metres altitude, the thickness of the atmosphere is even less, atmospheric pressure is also smaller (it's no more than 0.4 bar) and water boils at an even lower temperature: 75°C.

Of course, if we leave eggs in water at only 75°C for ten minutes, they won't be cooked at all.

Our conclusion is that to hard-boil an egg, we must supply it with enough energy. The greater the altitude, the lower the boiling point of water becomes, and the greater is the need to boil eggs for *long periods* in order to supply them with enough heat to cook.




**These effects where the boiling temperature varies with pressure are very important if we need a good understanding of refrigeration systems. This is why, in the next chapter, we'll look at them in more detail...**

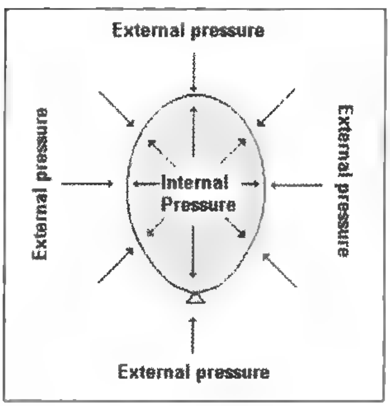
# THE PRESSURE-TEMPERATURE RELATIONSHIP

In a litre of water, there are an enormous number of water droplets, and each of these droplets is itself made up of a huge number of water molecules.

To define a water molecule, let's say that it's the smallest drop of water that can exist, and we'd need an extremely powerful electron microscope in order to see one!

Every water droplet can be compared to a balloon (the party type that keeps children happy - until they burst!).

When you blow into a balloon, you'll notice that it expands. What happens is that the membrane wall of the balloon stretches as a result of the pressure of air that you blow into it.

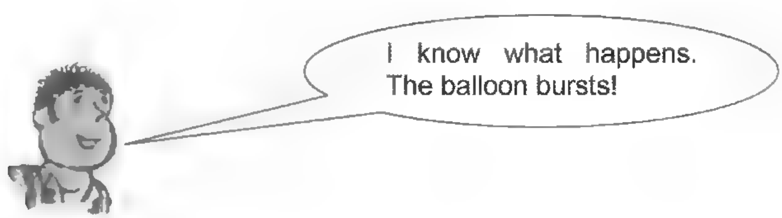



When you blow up a balloon, two pressures act upon the membrane:

1). An internal pressure developed by the air that you've blown into it.

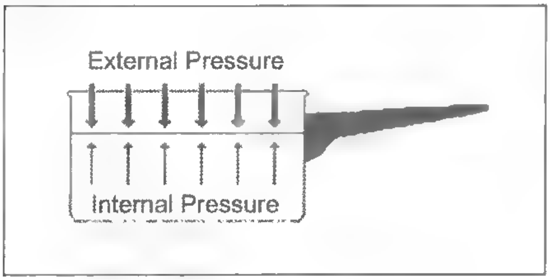
2). Atmospheric pressure that exists around us at all times.

And what happens if we increase the internal pressure a bit too much?




Correct. If you blow too hard, the internal pressure becomes too great, and the balloon explodes. *Don't you ever explode when someone puts you under a bit too much pressure?*

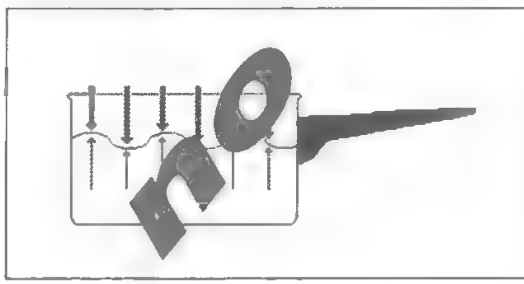
In exactly the same way as the balloon we've just seen, every water droplet is also exposed to the action of two pressures: one external and one internal.




When we put water in a saucepan, we observe that the surface of the water stays absolutely flat and horizontal. Also, the water tends to stay entirely at the bottom of the pan (and doesn't generally splash into your face).

I'm going to ask you an apparently stupid question: *why?*

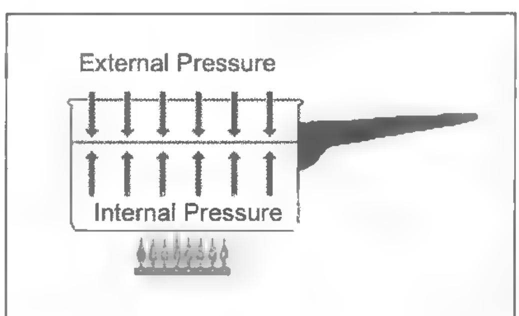
Let's consider this: we know that an external pressure and an internal pressure are being exerted on every point on the surface of the liquid. *Note that in our example the external pressure is due to atmospheric pressure.*




Firstly, if these pressures weren't exactly identical at all points, the surface of the water wouldn't be flat, but in fact, undulating (with dents and lumps); this isn't the case

The pressures are therefore uniformly distributed at all points, and this is why the water surface remains perfectly flat and horizontal.

Of course, as long as the internal pressure of the water remains less than or equal to the external pressure (that is, atmospheric pressure), all the water will remain in the saucepan.

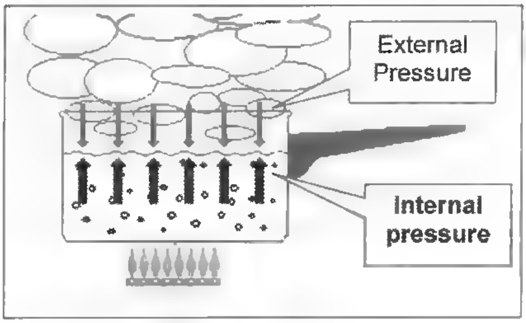



Now, if we place the pan on a burner, the water will receive energy in the form of heat.

This energy causes an increase in the internal pressure of the water, *just as the air that you blow into the balloon causes the membrane to stretch.*

Gradually, as the burner heats the water, the internal pressure of each droplet increases more and more. However, the external pressure (that is, atmospheric pressure) doesn't change

*Are you beginning to get the picture?*




As soon as the internal pressure becomes great enough, the external pressure won't be sufficient to keep the water in the saucepan.

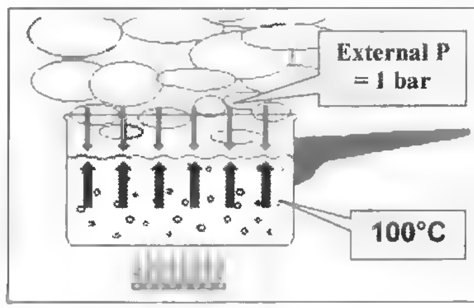
At this point, the water molecules break apart from each other, and become gas molecules which, being lighter than air, leave the saucepan.

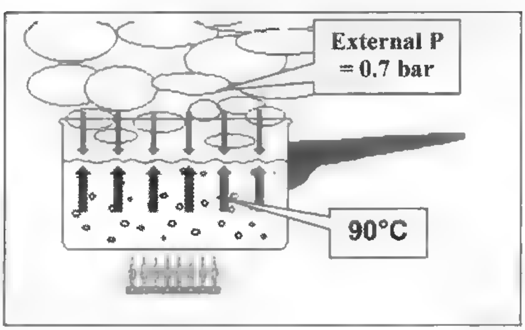
This is why large bubbles of water vapour (steam) burst out from the surface, causing a drop in the level of liquid in the pan.

Although we continue to heat the saucepan, the temperature is no longer rising. All the heat from the stove only serves to make the water molecules escape and causes the change of state: *This is our old friend the vaporisation step!*

At sea level, atmospheric pressure, and hence the external pressure, is 1 bar.

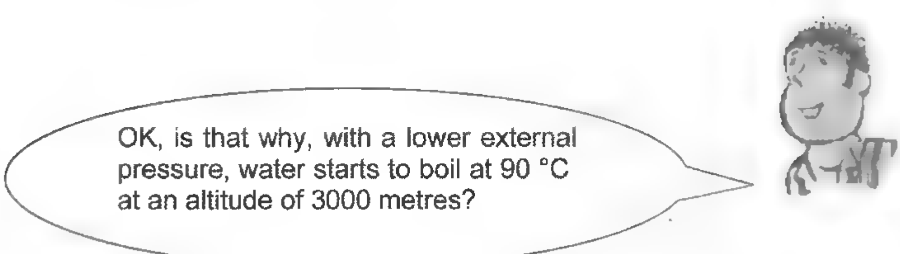
Therefore, we need to raise the temperature of the water to 100°C so that the internal pressure can overcome the atmospheric pressure, and so that boiling can start to occur.



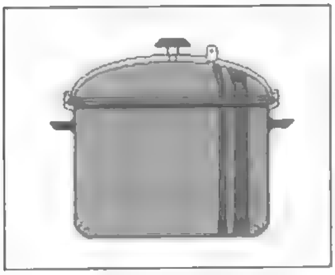

In the mountains, as the altitude increases, the thickness of the atmosphere decreases. This causes a reduction in atmospheric pressure, and so a reduction of the external pressure.

**As the external pressure decreases, the internal pressure needed to allow the water molecules to escape from each other also becomes smaller. As a result, water will start to boil at less than 100°C.**

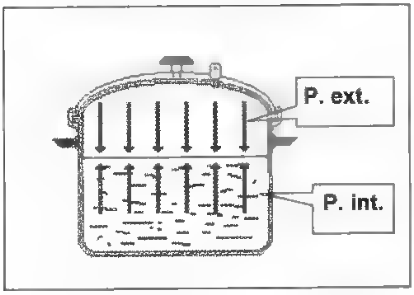


Good, that's perfectly correct! But let's see; what do you think the boiling point of the water would be if the external pressure increased: *would it stay at 100°C, would it increase, or would it decrease?*

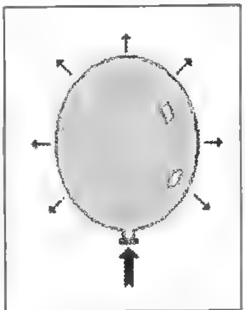
*What do you think? Just to put you on the right track, think about the operating principles of a pressure cooker.*



Everyone knows what a pressure cooker is: a special saucepan equipped with a sealable cover. When you put water in the pressure cooker, and then seal the lid, *the water at the bottom of the pressure cooker and air at atmospheric pressure remain trapped inside the cover.*




As you heat the pressure cooker, the temperature of the water rises. At the same time, the internal pressure of the water increases. Whilst the water temperature remains at less than 100°C, the external pressure (inside the pressure cooker) remains sufficient to keep the water in liquid form at the bottom of the cooker.



Once 100°C is reached, only a tiny amount of extra energy is needed to allow the first water molecules to escape from each other. These molecules of vapour (which are water in its gaseous form) remain trapped inside the cover of the pressure cooker. There is therefore more and more gas inside the cover. This produces exactly the same effect as when you blow air into the balloon (that is, you add some gas to the interior of the balloon). The pressure inside the cover increases.

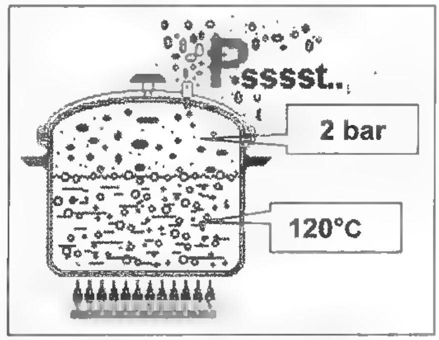
*At this point, since the external pressure has increased, boiling is prevented, despite the water being at 100°C.*

However, as the burner continues to heat the pressure cooker *the internal forces of the water molecules continues to increase.* As soon as they become greater than the external forces, then boiling occurs at a temperature now in excess of 100°C.

The extra water vapour that this releases also remains trapped inside the cover of the pressure cooker, so the external forces increase further. Boiling is once again prevented, despite the fact that the water is at a temperature greater than 100°C, *and so on, and so on…*

As this process continues, the water temperature gradually rises as the external pressure increases.


I understand that OK, but if the pressure in the pressure cooker increases indefinitely, it's dangerous. It might explode!




No, it can't be allowed to continue to rise indefinitely. In fact, the manufacturers fit a safety valve in the pressure cooker cover. If the pressure becomes too great, the valve opens and releases steam. When this happens, just as a balloon deflates when air is released from it, the pressure is kept at a reasonable level.

This valve opens to release water vapour as soon as the pressure inside the pressure cooker reaches about 2 bar. At this pressure, the balance with the internal forces of the water is obtained at about 120°C.

In this way, the valve maintains 2 bar in the pressure cooker, and the water temperature stays at about 120°C. Of course, dishes cook much more quickly at 120°C than if they were in a traditional saucepan at atmospheric pressure, where the water is only at 100°C.

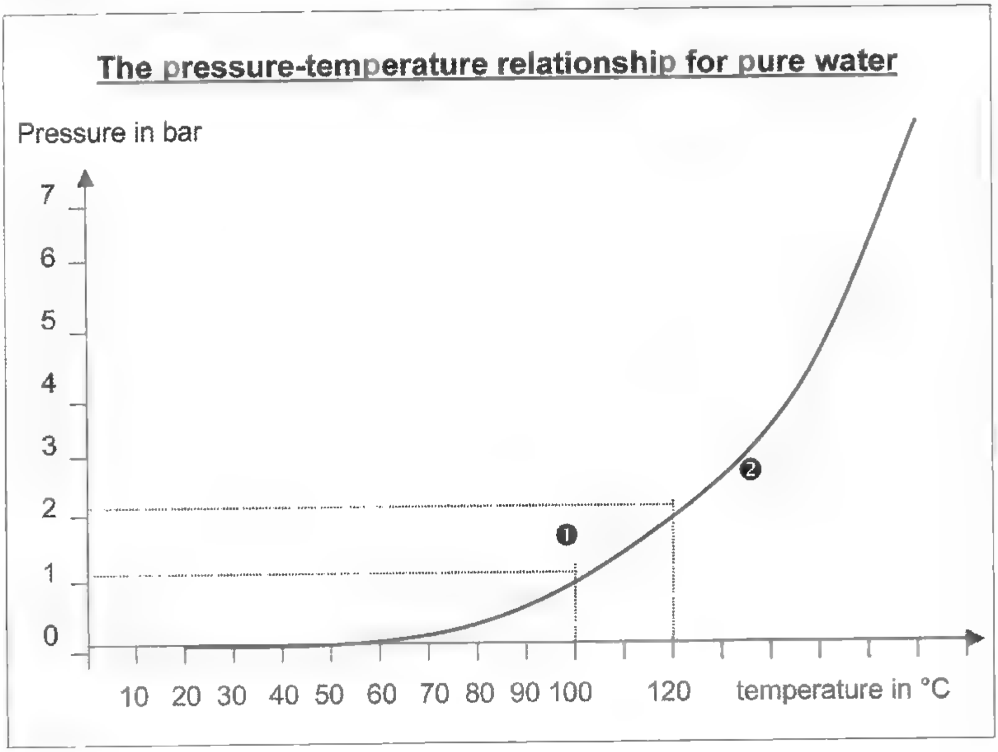
OK then, if I've got it right the boiling temperature of water changes in line with pressure. They increase or decrease together.

That's correct. Every time the pressure changes, the boiling temperature also changes. In effect, for every pressure, there is a corresponding boiling point; this is what is known as:

***The pressure-temperature relationship.***

To use the language of the industry, from now on we won't speak about boiling, but rather of vaporisation or evaporation (*don't panic*: all these terms mean the same thing).

The diagram below is the pressure-temperature relationship for pure water. It shows the evaporation temperature of water as a function of the external pressure.




In this diagram, we can see that at 1 bar (that is, atmospheric pressure), water boils at 100°C (point ❶). We can also see that at 2 bar, water boils at 120°C (point ❷), and so on...

This diagram confirms that if the pressure increases, the evaporation temperature also increases.

Similarly, if the pressure falls, the evaporation temperature decreases likewise.

**Evaporation temperatures and evaporation pressures always vary in the same direction. They increase and decrease together. They are linked.**

Of everything that we've seen up until now, certain essential points are especially important:

- **There can only be transfer of heat between two bodies if those two bodies are at different temperatures.**

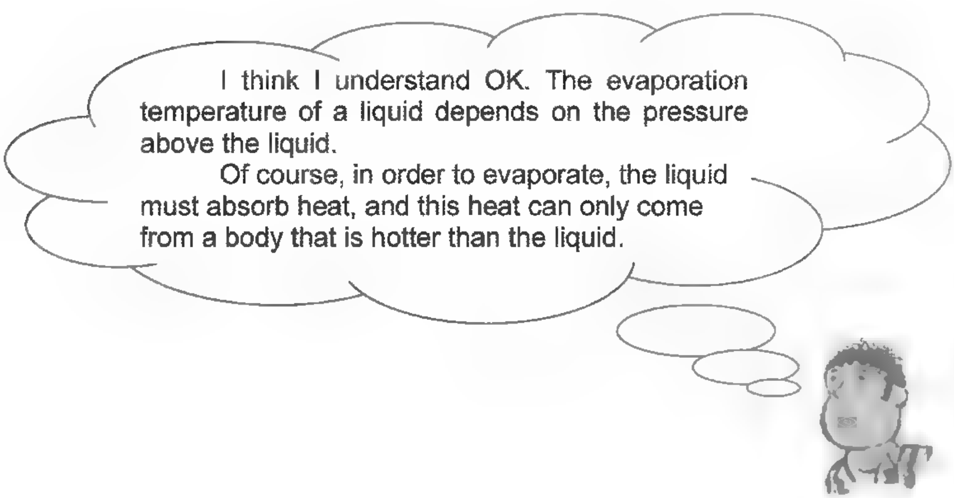
- **Heat always flows from the hotter body to the colder body.**

- **The change from the liquid state to the vapour state is called evaporation.**

- **In order for a liquid to evaporate, it must absorb heat.**

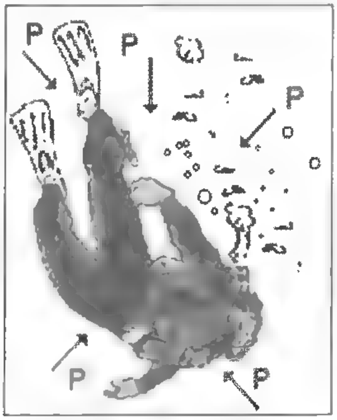
- **During the evaporation of a liquid, the temperature remains constant. The heat absorbed by the liquid during evaporation is called the <u>latent heat of evaporation.</u>**

- **Evaporation temperatures and pressures always vary in the same direction. They increase and decrease together. They are linked.**




*And if you haven't understood this chapter, or if you are in any way unsure about something, don't hesitate to read it over once more: the processes of evaporation are essential in the operation of a refrigeration system.*

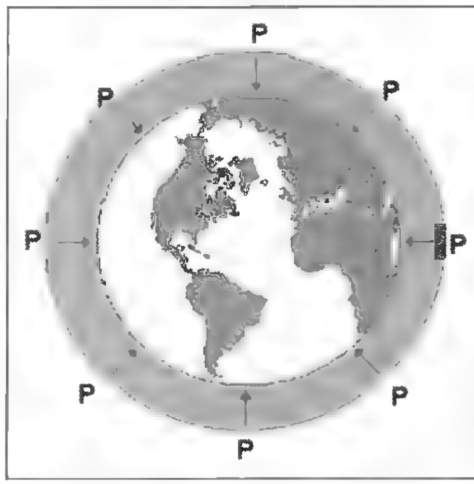
# RELATIVE PRESSURE & ABSOLUTE PRESSURE




We've already discussed the topic of pressure, but before continuing, it's important that we are absolutely clear about this concept.

Do you remember how the deeper a diver went in the water, the greater was the pressure **P** that he was subjected to? Pressure, then, is due to the weight of the column of water found above the diver.

The deeper the diver descends, the bigger the column of water gets, and the more the pressure increases. (it increases by about 1 bar for every ten metres in depth).

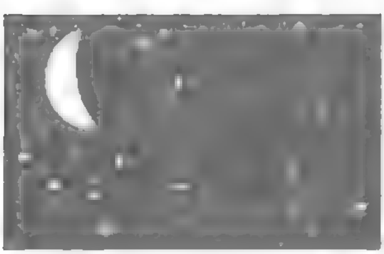



Similarly, atmospheric pressure is due to the height of the column of air above us. The higher the column of air, the higher the atmospheric pressure.

Unless we dig down into the earth, the height of the column of air is greatest at sea level.

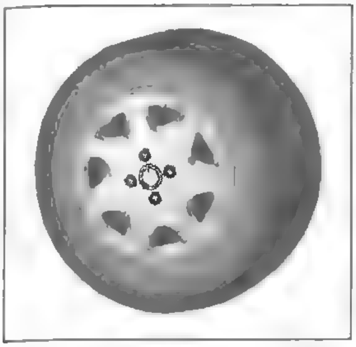
Consequently, it's at this point that atmospheric pressure is greatest: 1.013 bar.

As a mountaineer climbs, he gains altitude, and the height of the column of air above him diminishes. This is why atmospheric pressure decreases as we go up in altitude: it falls to about 0.7 bar at 3000 metres.



After lift-off, when a rocket leaves the atmosphere and starts to orbit, atmospheric pressure no longer exists. *There is no air or gas of any kind at all*: there is a **total vacuum**! By definition, a total vacuum is the lowest pressure that can exist. *We say then that the pressure is 0 bar absolute.*

**When we compare pressures to absolute vacuum, we speak about absolute pressures. *An absolute pressure is always greater than or equal to 0 bar.***



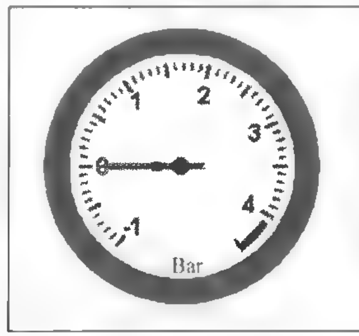
When you need to check the inflation pressure of your tyres, you go to a service station to use the test device that we call a pressure gauge.

Think about the following question for a moment: what is the pressure shown by the needle of the gauge before you connect it to the tyre valve?

I'm pretty sure that the gauge needle reads 0 bar!

Indeed, before it's connected to the tyre valve, the pressure gauge actually measures atmospheric pressure, and yet the needle shows 0 bar.

Although we are not in outer space, the gauge needle reads 0 bar!




It's true; the needle does actually show 0 bar. But why doesn't it read 1 bar, that is, the value of atmospheric pressure?


***For once,*** because atmospheric pressure exists all over the surface of the earth, **the whole world has agreed that every pressure gauge open to the air reads 0 bar**. Just remember this fact, and this won't be a problem!

*If this is so, if we take this pressure gauge into space, what pressure would it show?*


We know that atmospheric pressure equals 1 bar at sea level. If a pressure gauge shows 0 bar when it measures atmospheric pressure, then when it is in a total vacuum, it will show 1 bar less than this, that is – 1 bar.

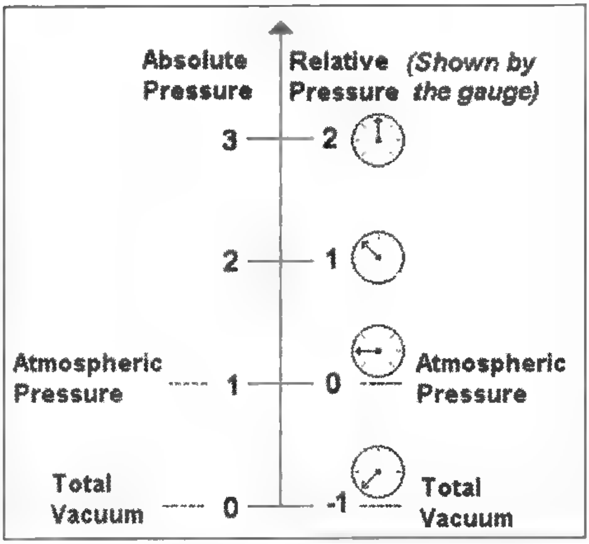
*Just remember that in general, pressure gauges are graduated to read 0 bar at atmospheric pressure.*

Experts will often talk about pressures as being relative pressures, and sometimes as absolute pressures. Pressures are described as **absolute** when they are **measured relative to total vacuum**. They are called relative pressures, or **gauge pressures**, when measured relative to atmospheric pressure.

On the graph opposite, you can read absolute pressures off the left-hand scale (that is, pressures relative to absolute vacuum).

*Shown on the right hand scale are relative pressures (that is, those which a pressure gauge would show relative to atmospheric pressure).*

Thus, in a total vacuum, pressure is 0 bar absolute or -1 bar gauge.




Atmospheric pressure corresponds to a pressure of 1 bar absolute or 0 bar gauge.

**Pressure gauges are amongst the most important tools used by a refrigeration engineer, and we must be proficient in their use. It is important to remember that the pressures they show are relative, that is, they are relative to atmospheric pressures.**

From what we've seen then, we can state that:

**Absolute pressure = gauge pressure + 1 bar**

That's why a pressure of 2 bar shown on a gauge corresponds to 3 bar absolute...

# IS WATER A GOOD REFRIGERANT?

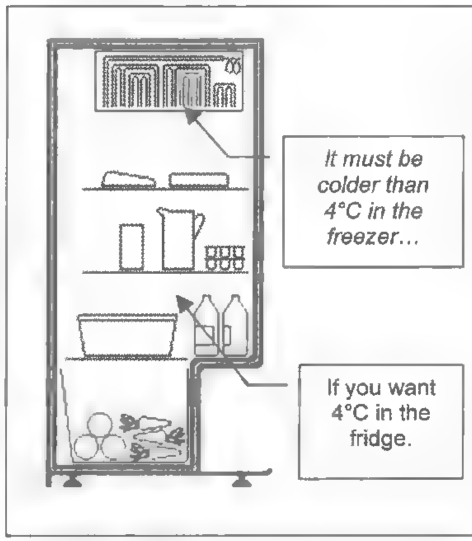
Let's remind ourselves of these two basic rules:

1. **There will only be transfer of heat between two bodies if those two bodies are at different temperatures.**

2. **Heat always flows from the hotter body to the colder body.**

In our fridge, if we wish to keep the temperature of the food at 4°C, then the temperature of the 'cold' heat exchanger must be less than 4°C.

**In order to maintain 4°C in a refrigerator, the temperature of the 'cold' heat exchanger must be less than 4°C.**



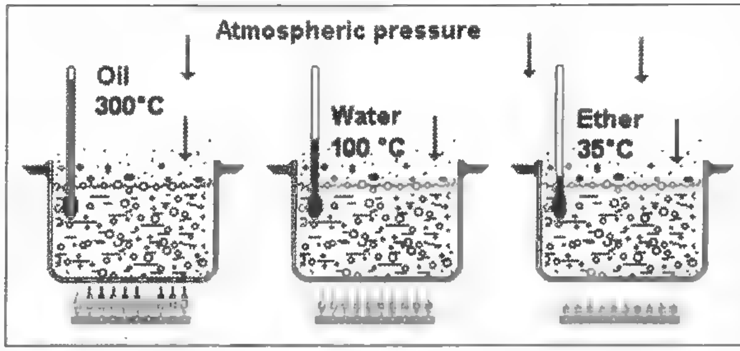

We've seen that it's possible to lower the temperature of evaporation of water by lowering the pressure (for example, by increasing in altitude). Then why couldn't we make water evaporate at, say, 0°C in the freezer of our fridge?

In order to make water boil at 0°C, the pressure needs to be very low indeed. Therefore, unless we can take our fridge into outer space, or use very sophisticated (and therefore very expensive) vacuum pumps, we will have to find a fluid other than water for our fridge.

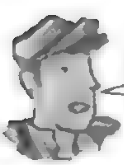
You are obviously aware that all liquids don't have the same boiling temperature. Then why not use, say, an oil? For example, cooking oil boils at approximately 300°C. Unfortunately, although this temperature is perfect for making potato chips, it would be too high for our fridge.

What about using ether? Ether evaporates at 35°C (at atmospheric pressure of course). This is already better than oil, but with a freezer at 35°C, you couldn't reduce the temperature in the fridge to less than this value of 35°C. *This wouldn't be particularly good for keeping your drinks cold !*

So in order to make ice cubes in our refrigerator, we must find a substance whose boiling point is less than 0°C.




Perhaps I'm being a bit stupid, but why can't we use ether? If we reduce the pressure so that it's below atmospheric pressure, the external forces will decrease, and just like water at high altitudes, the evaporation temperature of ether will also fall. Can't we get to temperatures below 0°C like this?



*In theory*, your reasoning is absolutely correct, and it should actually work like this.

However, *in practice*, there are a number of problems that mean that ether is of little interest as a refrigerant. In fact, you won't find any commercial refrigerators that run using ether, especially since refrigeration engineers have much more interesting refrigerant fluids available to them.

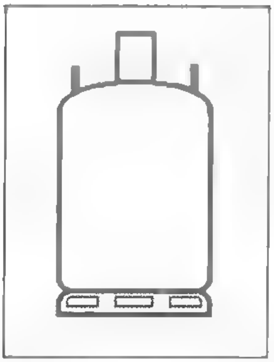
OK, let's forget ether, but tell me, what are these interesting refrigerant fluids that you're talking about?

*What are these mysterious fluids used by refrigeration engineers? We'll begin to see in the next chapter…*

# REFRIGERANT R22

The refrigeration industry makes use of a large number of fluids, called *refrigerants*, which all evaporate at low temperatures when they are at atmospheric pressure.

These fluids are still sometimes known as "freons". You might know that the word Freon is in fact the trade name used by the "Dupont" company for these materials. The Elf Atochem group, for example, uses the name "forane" for these materials. In practice, each manufacturer gives their own refrigerants a trade name.



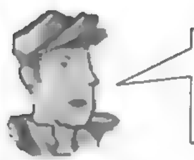
All these refrigerants are sold and marketed in a series of different size containers, exactly like the cylinders of butane or propane that you may have perhaps had occasion to use for cooking or heating.

In order not to get lost amongst the different brand names, refrigerants are identified by the letter **R** (R for **R**efrigerant).

For example, R22 is one of the refrigerants most commonly used in air conditioning, and is the one we'll be using as an example throughout our study. It is known by such names as: Freon 22, Forane 22, Suva 22, etc., according to the manufacturer.

It is very important to understand that R22 is absolutely identical whoever the manufacturer is. This situation is a bit like buying petrol from Total, BP, Elf etc.

We can, therefore, mix Freon 22 with Forane 22 for example; the two materials are absolutely identical.



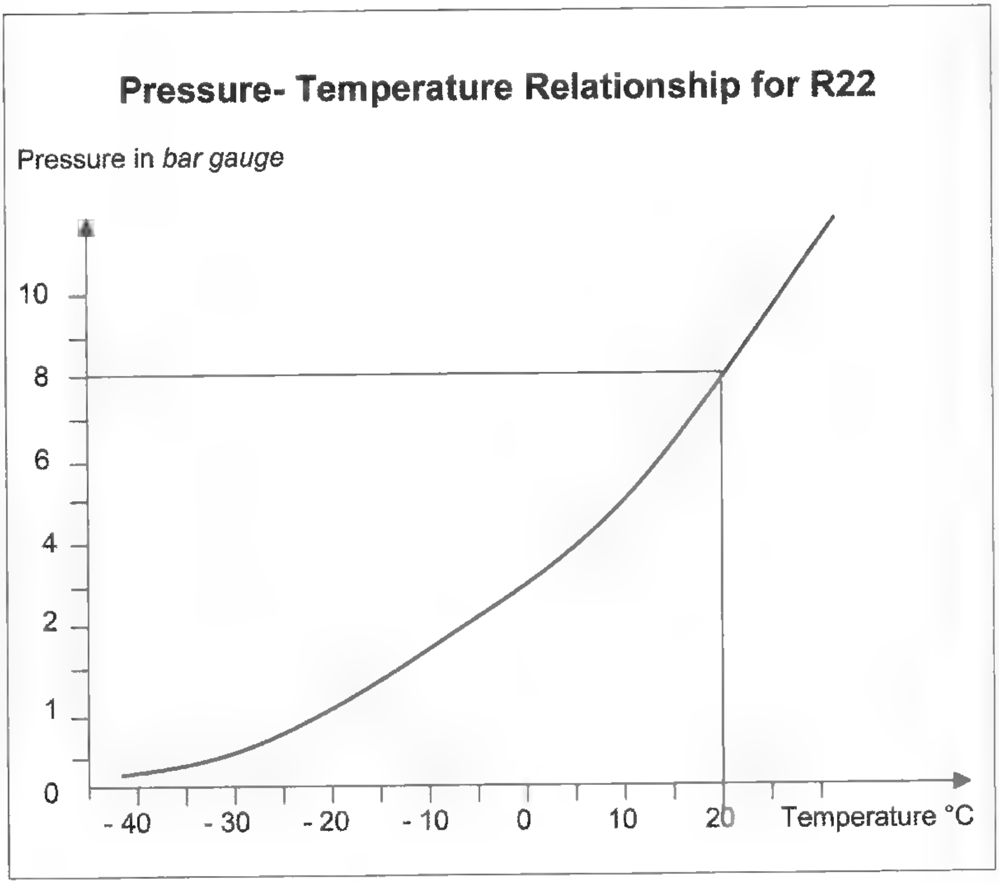
Remember that the characteristics of **R22** are absolutely identical whatever the trade name is, or whoever the manufacturer is.

**R22 is particularly interesting as it evaporates at -42°C at atmospheric pressure** (compared with 100°C for water, 35°C for ether or 300°C for cooking oil).

Because of its low evaporating temperature, R22 allows us to obtain a temperature of less than 0°C quite easily in the freezer of our fridge. This, remember, is our objective.

The pressure-temperature relationship for refrigerant R22 follows exactly the same general rules as that of water. The lower the pressure above the liquid becomes, the lower the evaporation temperature (and vice versa).

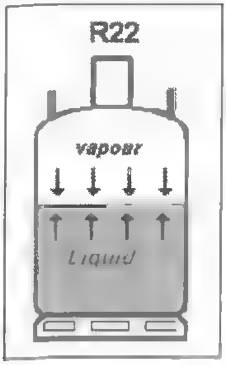
To give you a feeling for this, the diagram below shows you the pressure-temperature relationship for R22 from –40°C to +20°C.




You will see from the diagram that at 0 bar gauge (that is, at atmospheric pressure), the evaporation temperature of R22 is –42°C. At 8 bar, its evaporation temperature rises to about 20°C.

You can see from this diagram then, that as the evaporation pressure increases, the evaporation temperature correspondingly increases (you should know the reasons why: remember the explanation involving internal and external pressures?).

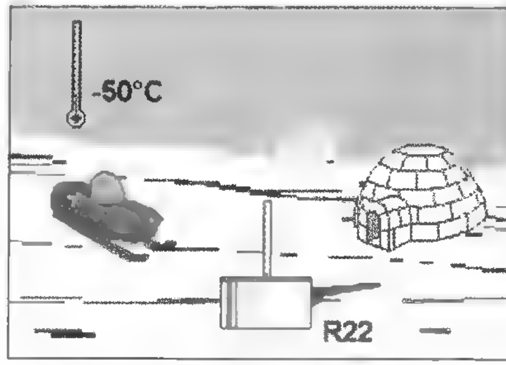
Thus, the evaporation pressure and temperature of R22 are linked, and they change in the same direction, exactly like those of water did, but with a pressure – temperature relationship that involves very different values.



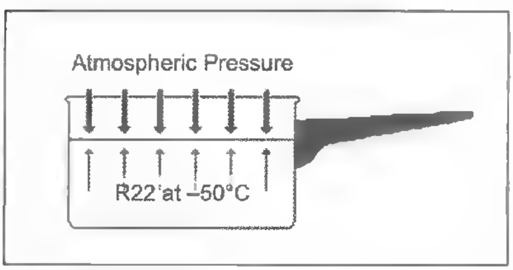

Consider the interior of the cylinder of R22 opposite. There is liquid present in the bottom of the container, and vapour above it. The internal pressure of the liquid is in equilibrium with the external pressure of the vapour. If the temperature of the cylinder increases, the refrigerant pressure also increases in line with the pressure-temperature relationship, to give about 8 bar at 20°C, 11 bar at 30°C, 14 bar at 40°C and 19 bar at 50°C.

*So it's better to avoid storing cylinders of refrigerant in direct sunlight, or close to a source of heat, in order to avoid any dangerous over- pressurisation.*

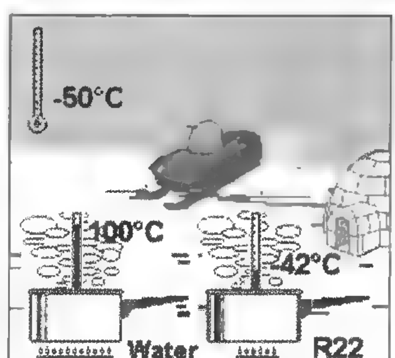
The author knows from experience that some readers will find it difficult to visualise how a refrigerant like R22 is a liquid that can evaporate at -42°C at atmospheric pressure.




To help us throw some light on this phenomenon, let's imagine ourselves inside a cold room where the temperature is -50°C, or even imagine yourself at the North Pole in the middle of winter. Under these sorts of conditions, it will be possible to pour R22 into a saucepan, where it will remain completely in the liquid form.

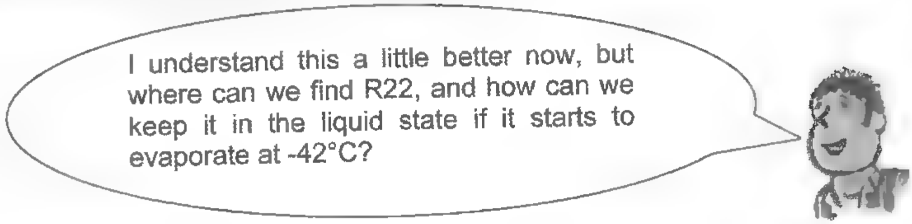



What happens is that the temperature of the R22 being at minus 50°C, the internal forces are weaker than the external forces (which correspond to atmospheric pressure). The surface of the liquid contained in the saucepan remains flat and still.



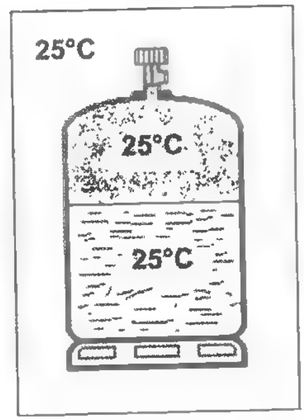

To make the R22 evaporate, we only need to heat it on a burner and so increase the internal forces. When the temperature reaches -42°C, evaporation will begin.

*You should remember that under these same conditions, water starts to evaporate at 100°C, since the external forces correspond to atmospheric pressure.*



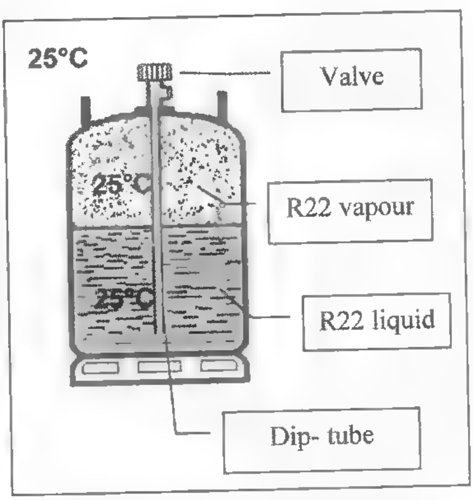

To answer Charlies' question, we'll take another example from everyday life. Do you know the evaporation temperature of butane gas? At atmospheric pressure, it evaporates at –0.5°C. You will have certainly come across butane before.

Commercial butane for heating and cooking is sold in cylinders. Each cylinder holds a mixture of liquid and gaseous butane. If the cylinder only contained butane in the vapour state, it would need changing much too often! The temperature of this mixture needn't always be at 0.5°C. Generally the temperature of the cylinder is the same as its surroundings. For example, if it is 25°C on the outside of the cylinder, then the butane is also at 25°C on the inside.




It seems that there is a mixture of liquid butane (at the bottom) and gaseous butane (at the top). But shouldn't the butane be completely vaporised at 25°C? *What do you think?*

Let's examine the cylinder of R22 opposite. It's nearly identical to the cylinder of butane that we've just studied, but in addition it is fitted with a dip-tube.




This tube allows us to draw liquid R22 from the bottom of the cylinder. In contrast to butane or propane (which are used in their gaseous forms), we are more interested in R22 in its liquid form.

But what exactly is happening in this cylinder?

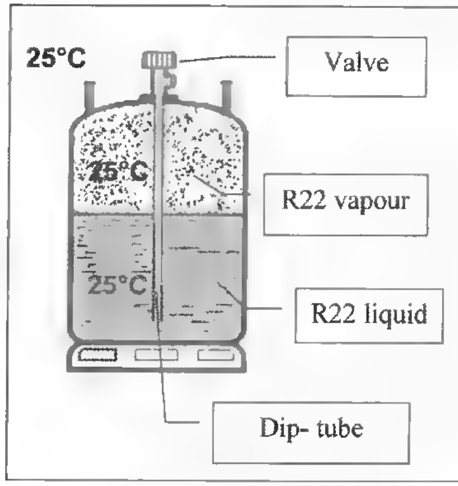
It seems that there is a mixture of liquid R22 (in the bottom) and gaseous R22 (at the top). But, at 25°C, shouldn't all the R22 be vaporised?

*What do you think?*

R22 is sold in cylinders which are very similar to those used for butane or propane.

These cylinders are just like a pressure- cooker without a safety valve. The energy provided by the surrounding temperature causes some of the R22 in the cylinder to evaporate, until equilibrium between the internal and external forces is achieved.

However, unlike the pressure–cooker, there is no safety valve to limit the pressure developed inside the cylinder




In this case, when the surrounding temperature starts to increase, what will happen to the pressure of R22 inside the cylinder? Will it increase, decrease or remain constant?

*If you like, work out your answer to this before you continue…*

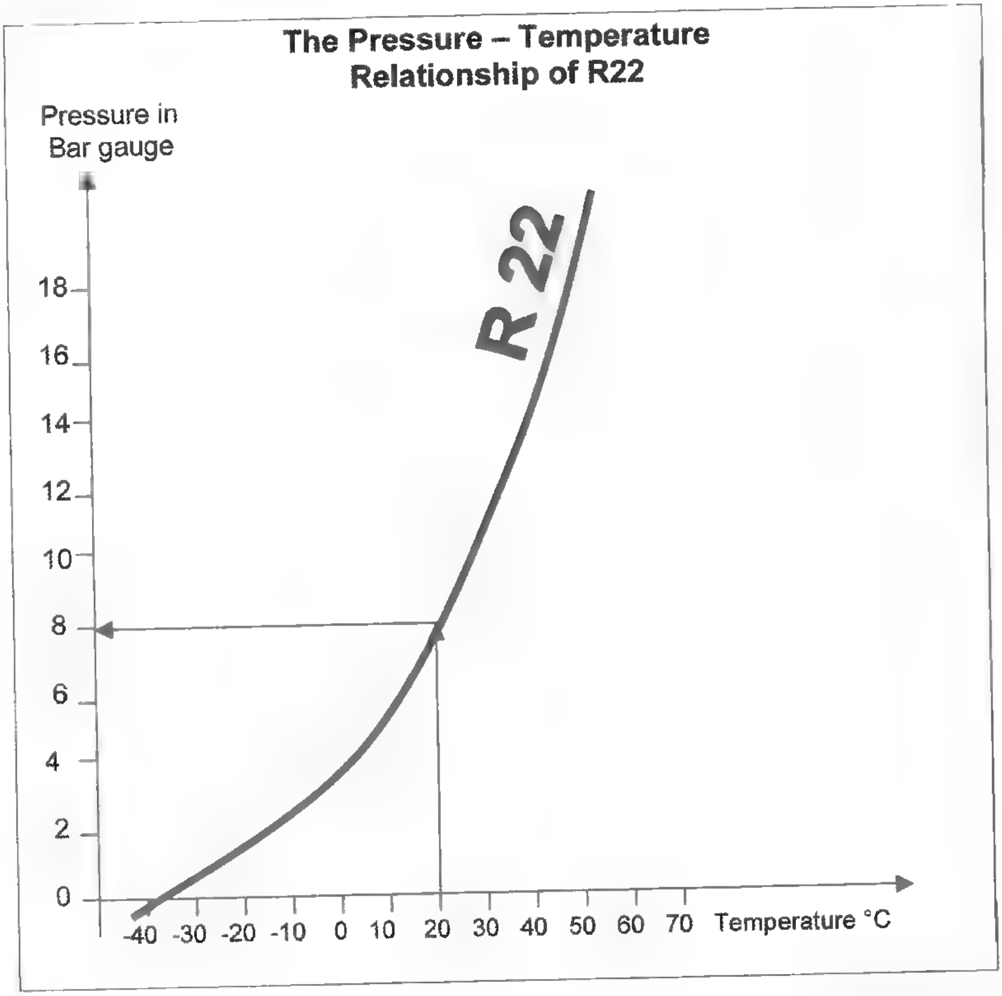
I expect that it's the same as with water, and that the pressure- temperature relationship plays a part!

Absolutely! The R22 obeys the same laws of nature as other fluids: its pressure varies with temperature. But you haven't really answered the question…!

OK then, if the surrounding temperature increases, the R22 pressure inside the cylinder increases. I expect that it's important to know all about the pressure-temperature relationship for R22!

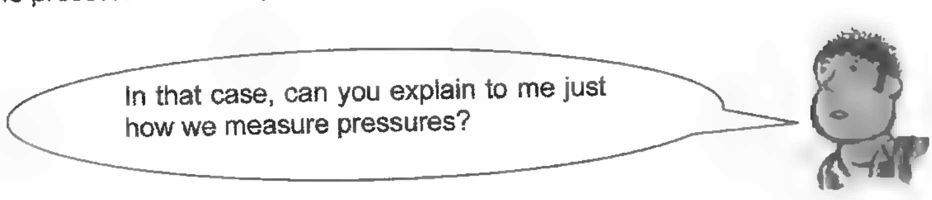
*Although it isn't important to memorise all the values in the pressure-temperature relationship of R22, if we want to maintain a fridge system, we must be able to at least understand it in general terms!*

*Let's look again at the pressure temperature relationship of R22.*




Let's assume that the ambient temperature is 20°C for the cylinder's surroundings. The R22 will then also be at 20°C and its pressure will therefore be 8 bar, as shown on the graph.

You can use the graph to verify that at atmospheric pressure, the evaporation temperature of R22 is –42°C. Furthermore, you can see (just as with water, butane and propane), that as the temperature of the R22 increases, the pressure increases, and vice versa.



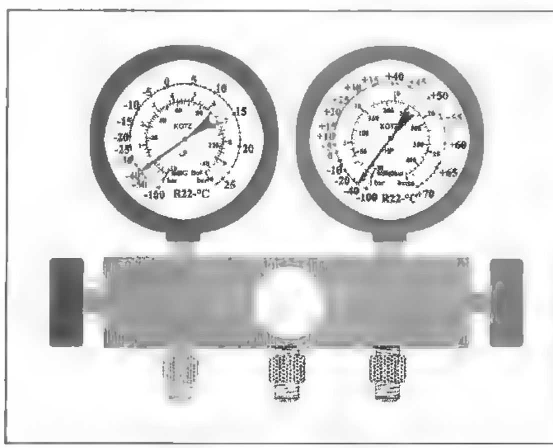
We use a pressure gauge to measure pressures. This is one of the most essential tools of the refrigeration engineer. Without a gauge, it's difficult to effectively check the correct operation of a system. A gauge shows us the operating pressures and temperatures of a refrigeration system.

Wait a minute! You're saying that a pressure gauge lets you measure pressures, and I agree with you. *But how does a pressure gauge measure temperature?* I'd say you measure temperatures with a thermometer!

You're right, you could use a thermometer to measure a temperature, and the pressure gauge is a device that allows you to measure pressures. However, a fridge engineer's pressure gauges are a bit special: they have a pressure scale, but also a temperature scale.

In fact, a fridge engineer's gauges <u>are</u> actually a device for measuring pressures. However, the dials of these gauges are slightly more complicated as they also show one or more temperatures.

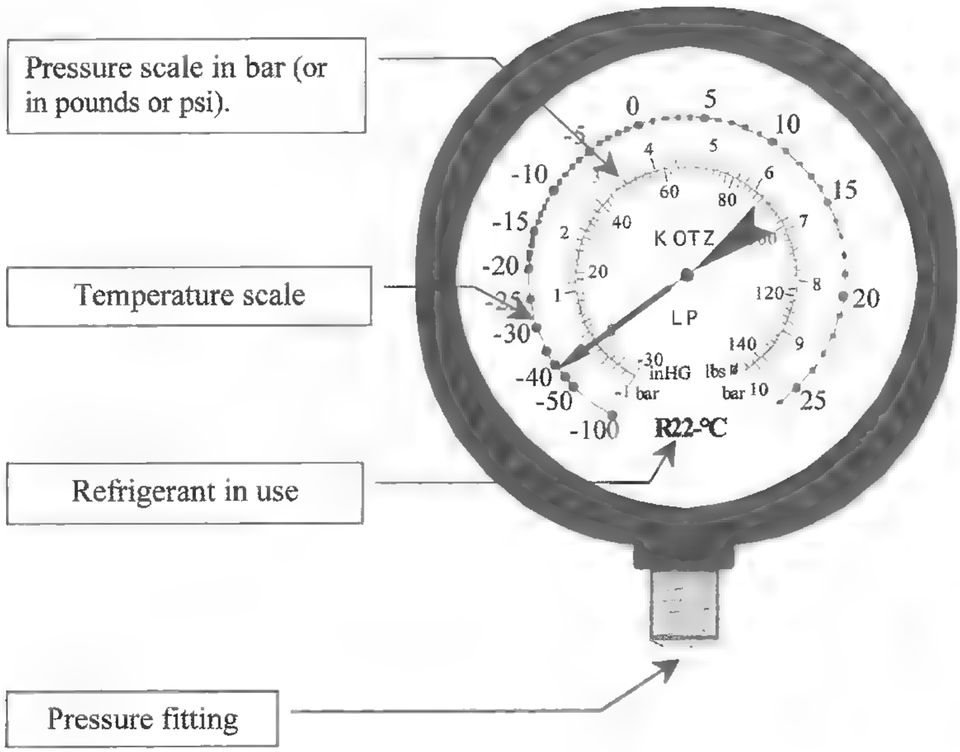
You can see opposite a view of one of the fridge engineer's principal tools: a "set of gauges", often called "a gauge manifold".



*In the following chapter, we will examine a set of gauges a bit more closely…*

# THE REFRIGERATION ENGINEER'S GAUGES

Examine the pressure gauge below: this is the type of gauge that is in daily use by fridge engineers.




We can see that this piece of equipment:

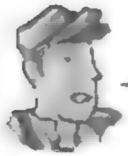
- Is fitted with a pressure connector used to connect it to an installation (by means of a special flexible hose).
- Has been given two pressure scales (we will use the bar scale) and a temperature scale. Note that the needle indicates 0 bar since the gauge is open to the atmosphere.
- Is graduated for refrigerant R22.

Before continuing our study of the fridge engineer's gauges, you should think about the two following questions:

**1) Why does the gauge read 0 bar when it isn't connected to a fridge system?**

*<u>Some advice:</u> For both these questions, try to think of a response before reading the answer provided!*

As the pressure connection is open to the atmosphere, the pressure gauge is measuring atmospheric pressure. Remember that, by convention, *all gauges are calibrated to 0 bar at this pressure.*



Remember, the needle may indicate 0 but the pressure isn't zero. The gauge is only comparing the pressure that it is measuring with atmospheric pressure.

I understand. The pressure gauge may be reading 0 but in reality it's measuring atmospheric pressure, that is, 1 bar. It's the old story of relative (or gauge) pressures and absolute pressures!

That's correct. Remember, then, that the pressure shown on a gauge is called *relative* or ***gauge pressure***. It is *relative* to the atmospheric pressure that has a true value of 1.013 bar absolute (we'll round this to a practical value of 1 bar).

| **Absolute Pressure = gauge pressure + atmospheric pressure (1 bar).** |
|---|

As a reminder, when the gauge shows 0 bar, the absolute pressure (expressed relative to total vacuum) is 0 + 1 = 1 bar.

So, if the gauge shows 4 bar (gauge pressure), the absolute pressure will be 4 + 1 = 5 bar.

All gauges show gauge pressure, but some technical information (that of refrigerant manufacturers, for example) will refer to absolute pressures. So exercise great care when you consult this type of literature if you want to avoid making mistakes. *If you have any doubts at all then read the appropriate chapter starting on page 40.*

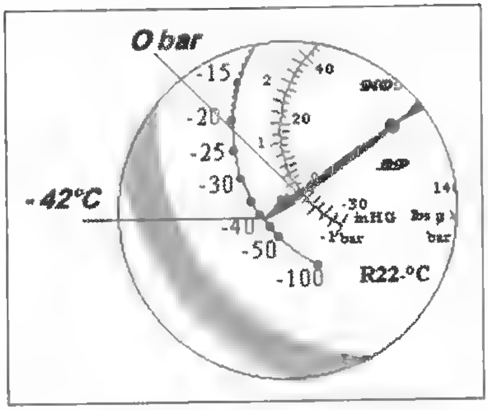
**2) Why does the needle indicate –42°C on the temperature scale when the gauge isn't connected to a system?**

We've just seen that a gauge that isn't connected (that is open to the atmosphere) measures atmospheric pressure. Therefore this corresponds to 1 bar absolute, that is, 0 bar gauge.

The needle therefore shows 0 bar.

Remember that at atmospheric pressure (that is 0 bar on the gauge), liquid water evaporates at +100 °C, liquid ether evaporates at +35°C and *liquid R22 evaporates at –42°C.*

Our gauge is calibrated for R22: the temperature scale therefore indicates -42°C, which is the temperature of evaporation of R22 at the pressure measured by the gauge (that is 0 bar gauge).




If the gauge had been calibrated for ether, say, then at 0 bar, the temperature scale would have shown +35°C.

### 3) Why is there a temperature scale at all on the refrigeration engineer's pressure gauges?

We've already discussed the pressure- temperature relationship diagram for R22 (page 48). On the fridge engineer's gauges it is a simple matter for the manufacturer to add, opposite the pressure scale, a temperature scale allowing us to read this relationship for any given refrigerant.

Because of this, every time that a fridge engineer measures a pressure, he can easily read off the temperature for the corresponding change of physical state at the same time. This is really much easier than reading this value from a diagram!

That's true! Especially if you've got greasy hands and you can't find the diagram! But you must have a gauge for every refrigerant, which isn't very practical either!

This is true. There are dozens of different refrigerants, and it isn't possible to show the pressure- temperature relationship for every one on the same gauge. They'd quickly become unreadable!

On many gauges, the manufacturers show 3 temperature scales, that is, three different refrigerants: this works well and makes things a lot easier!

## 4) Does the temperature shown by the needle always correspond to the temperature of the refrigerant?

*Firstly,* this is only true if you read the refrigerant temperature on the correct scale. For example, if you measure a pressure in an R22 system, you must read the temperature on the R22 scale, and not on the scales for R12 or R502 (which are other refrigerants).

*Secondly*, it is, of course, absolutely correct to say that the temperature scales give you the pressure- temperature relationship of the fluid in use. However, don't forget that this relationship only exists when a change of physical state is taking place.

***In view of what we've learned so far, the pressure- temperature relationship can only be applied under certain conditions. We must, in fact, be absolutely certain that the pressure being measured by the gauge actually corresponds to the evaporation stage during a refrigerant's change from a liquid state to a gaseous state.***

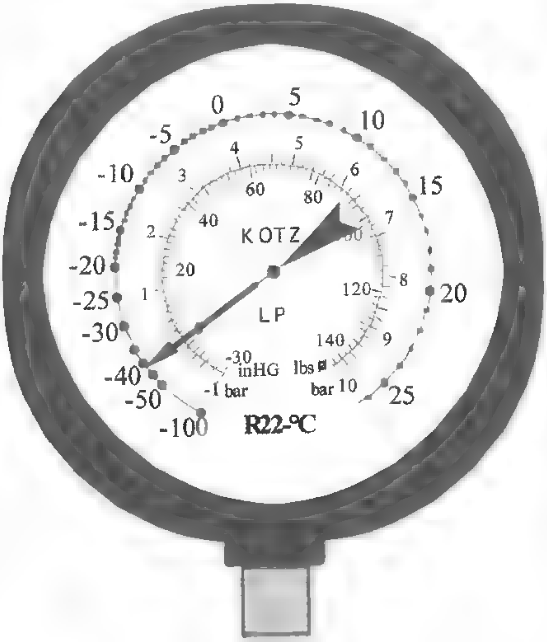
In effect then, the temperature shown by the gauge needle corresponds *at the pressure indicated*, to the temperature of the refrigerant, but **only if the refrigerant is actually undergoing evaporation.**

That's quite correct. However, if the refrigerant isn't undergoing a change of state, that is, if it isn't in the form of a liquid/vapour mixture, the temperature that the needle shows won't correspond at all to the true temperature of the refrigerant.

But *don't panic*, we'll be looking at this in more detail a little later, when we understand the refrigeration system a bit better.

***The refrigeration engineer's gauge allows us to measure the gauge pressure of a refrigerant. In addition, next to the measured pressure, the gauge indicates the evaporation temperature for the refrigerant at this pressure.***

## 5) What is the operating range of this gauge, i.e. what are the minimum and maximum operating pressures?




If we take a close look at the pressure scale in bar, we'll notice that the pressure is graduated down to a minimum of -1 bar and that maximum pressure is 10 bar.

Therefore, the operating range of this gauge is from –1 bar to 10 bar.

A pressure of –1 bar corresponds to a total vacuum. This is the lowest pressure that can exist.

In a similar manner, this gauge should not be used to measure a pressure greater than 10 bar under any circumstances.

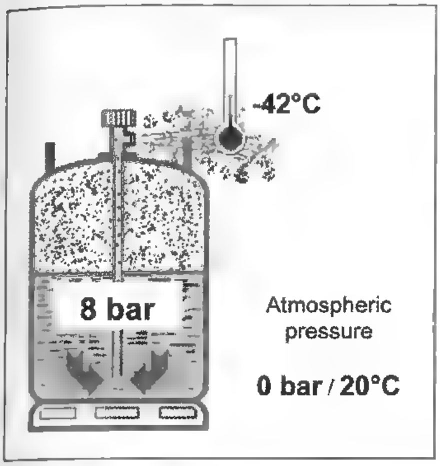
Do you remember the refrigeration engineer's gauge set referred to on page 49? In practice, the fridge engineer uses 2 types of gauge. One to measure **L**ow **P**ressures (the **LP** gauge shown above), and the other to measure **H**igh **P**ressures (the **HP** gauge graduated for pressures up to 30 bar). These two types of gauges are practically identical; only their operating range is different.

If a gauge is subjected to a pressure outside its operating range, there is a high risk of it being damaged, and afterwards of it giving false pressure readings. We should never try to measure HP with an LP gauge! In order to prevent mistakes like this, LP gauges are usually blue in colour and HP gauges are usually red.

**To avoid any possibility of damage, before using any measuring device (not only for pressure, but also voltage or current meters, for example), you are strongly recommended to check its operating range, and to establish beforehand the order of magnitude of the values to be measured.**

# THE EVAPORATION OF R22

Let's take a cylinder of R22 at an ambient temperature of 20°C. It's filled with a liquid-vapour mixture at 20°C which corresponds to a gauge pressure of 8 bar on the pressure temperature relationship of R22.

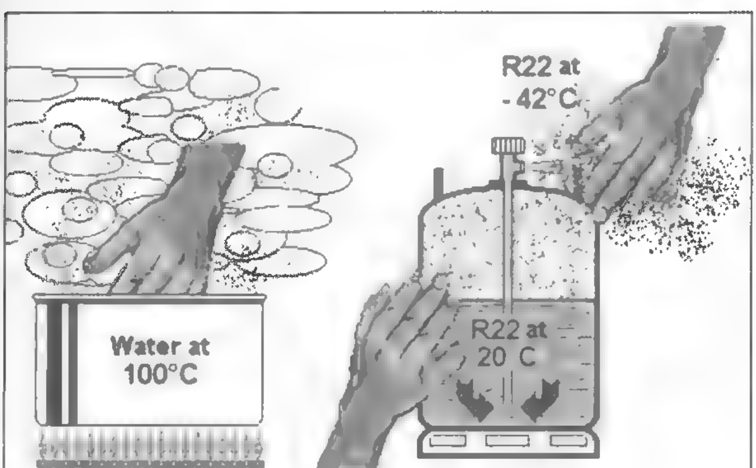



If we open the valve, then *liquid at 8 bar* immediately comes out of the cylinder *via.* the dip tube (there is no way that the vapour, trapped between the layer of liquid and the top of the cylinder can get out).

As it emerges from the cylinder, the molecules of liquid at 8 bar suddenly find themselves exposed to a much lower external pressure of 0 bar gauge. This rapidly causes the R22 to boil (as water does at 100°C) and change into vapour.

**But in order for it to vaporise, the liquid needs Heat.** *It will take this heat from any warmer material that it comes into contact with.*

For example, if we place a thermometer at the cylinder valve outlet, it reads -42°C, which corresponds exactly to the evaporation step temperature at atmospheric pressure.



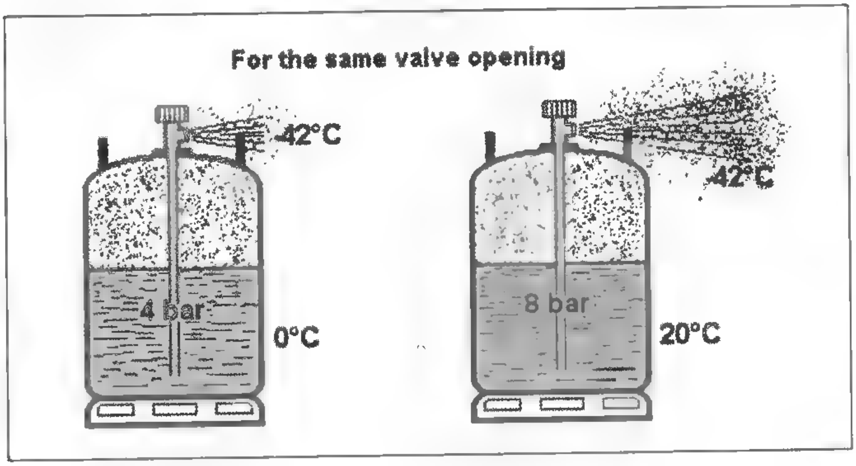

**DANGER:** if you plunge your hand at 30°C in boiling water at 100°C, this represents a temperature difference of 70°C. There is a great risk of being seriously burned.

***If you touch R22 at -42°C, this would represent a temperature difference of 72°C for your hand, and this would cause just as severe a burn as the situation above!***

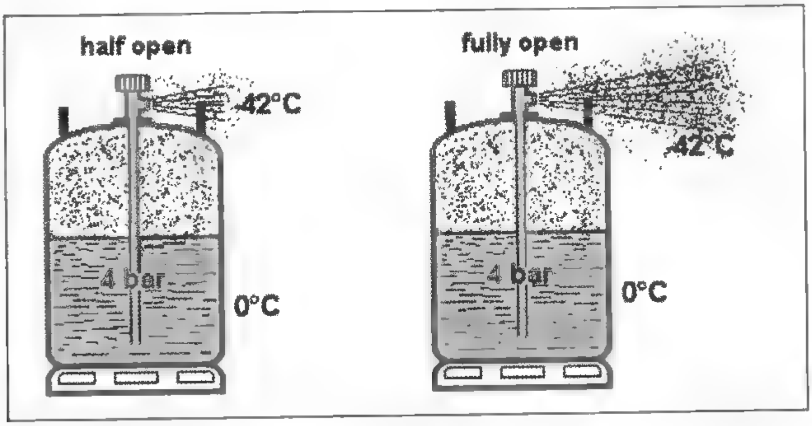
Of course, if you touch the outside of the cylinder at 20°C, there is no such problem.

We've just seen that R22 liquid at atmospheric pressure vaporises at –42°C by absorbing heat from its surroundings. To explain this effect in more detail, let's imagine that the temperature around the cylinder is 0°C. The pressure- temperature relationship for R22 indicates that the pressure in the cylinder is now 4 bar. Similarly if the ambient temperature was 20°C, the R22 in the cylinder will be at 8 bar.

*Look at the diagram below. For the same cylinder valve opening, it appears that the higher the pressure is inside the cylinder, the greater is the flow of liquid.*

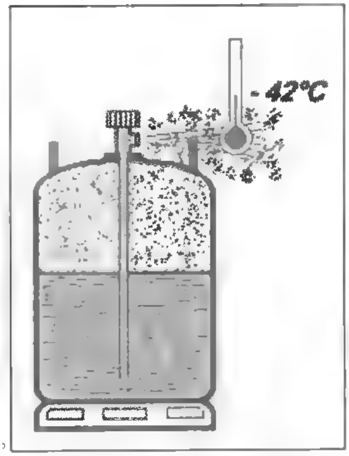



*In contrast, look at the diagram below. For the same pressures in the cylinders, we can see quite easily that the more the valve is open, the greater is the flow of liquid from the valve.*




***In conclusion then, the more the valve is opened, and the higher the pressure in a cylinder, the greater is the flow of liquid.***

*But for the R22 liquid that emerges from the cylinder to evaporate, it must be able to absorb heat.*




**In this example, the R22 absorbs the heat that it needs in order to evaporate from the surrounding air.**

***But since the R22 removes heat from the air, the air itself must become colder, as is shown here by the thermometer as it falls to – 42°C.***

**The vaporisation of R22 then enables the chilling of the air.**

**But the more liquid that emerges from the cylinder, the more heat the R22 must absorb heat in order to vaporise, and the greater will be the chilling of the surrounding air.**

*In brief then, the R22 contained in the cylinder has a capacity to absorb heat that depends on:*

1. The difference in pressure between the R22 and atmospheric pressure.
2. The extent to which the valve is opened.

So, in order to cool the air, the R22 must vaporise, and the more R22 liquid that vaporises, the more the surrounding air will be cooled.

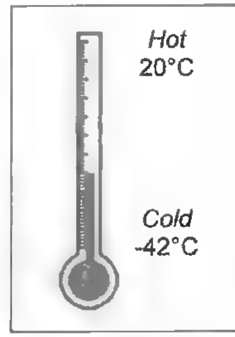
That's it, you've outlined the situation well. I would say that the refrigerating capacity (or cooling capacity) depends on the flow of liquid, but also on the pressure in the cylinder and the size of the valve opening.

We've just demonstrated a very important phenomenon: the refrigerating capacity (also called the cooling capacity) varies as a function of the quantity of refrigerant that is vapourised. The greater the quantity of R22 that is vaporised, the larger the refrigerating capacity.

*In the following chapter, we will see how to improve this system….*

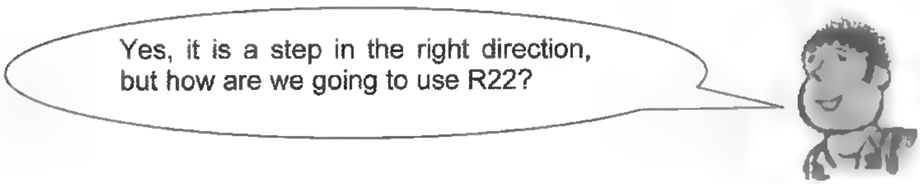
# WHAT HAPPENS IN THE COLD HEAT EXCHANGER?

Before answering this question, let's remind ourselves that in the last chapter we saw that there is a refrigerant called R22 that vaporises at -42°C at atmospheric pressure by absorbing heat.



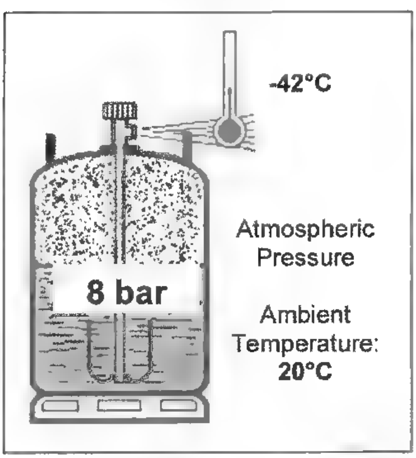

R22 is therefore capable of absorbing heat from any material whose temperature is greater than -42°C.

This is wonderful, as it just so happens that we want to chill foods in our fridge whose temperature is higher than this.




As we saw in the last chapter, if the pressure in the cylinder is greater than atmospheric, when we open the valve the R22 emerges in the liquid state after passing through the dip tube.

Let's examine the diagram below. At the valve outlet, we can see that the molecules of liquid at 8 bar are exposed to a much lower external pressure with a value of 0 bar gauge (that is, atmospheric pressure)

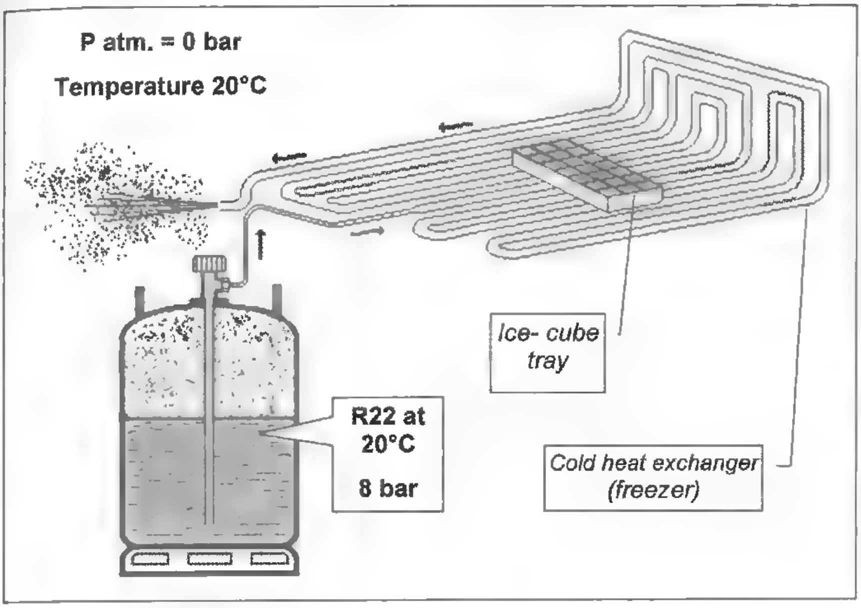



Since this external pressure is low in comparison with the internal pressure of 8 bar exerted by the liquid, the molecules of R22 liquid escape from each other and immediately evaporate, taking the heat required from the surrounding air.

This is why the thermometer placed at the outlet of the cylinder shows -42°C: the cooling of the surrounding air from +20°C to -42°C is simply due to the evaporation of R22.

In addition, we know that the cooling capacity (that is, the capacity to absorb heat) depends on the flow of liquid R22.

To obtain a better thermal exchange, the system could be improved by passing the liquid through a heat exchanger, as we have shown in the diagram below:




By partially opening the cylinder valve, we are able to regulate the flow of refrigerant through the freezer. As the freezer's outlet is open to the air, the pressure in this cold heat exchanger is effectively equal to atmospheric pressure. The R22 then travels from the cylinder to outside air by flowing through the freezer.

As the liquid R22 experiences a fall in pressure in the freezer, it vaporises. But in order to vaporise, the liquid needs heat, which it takes partly from the surrounding air, but also from the freezer and the ice cube tray placed on it.

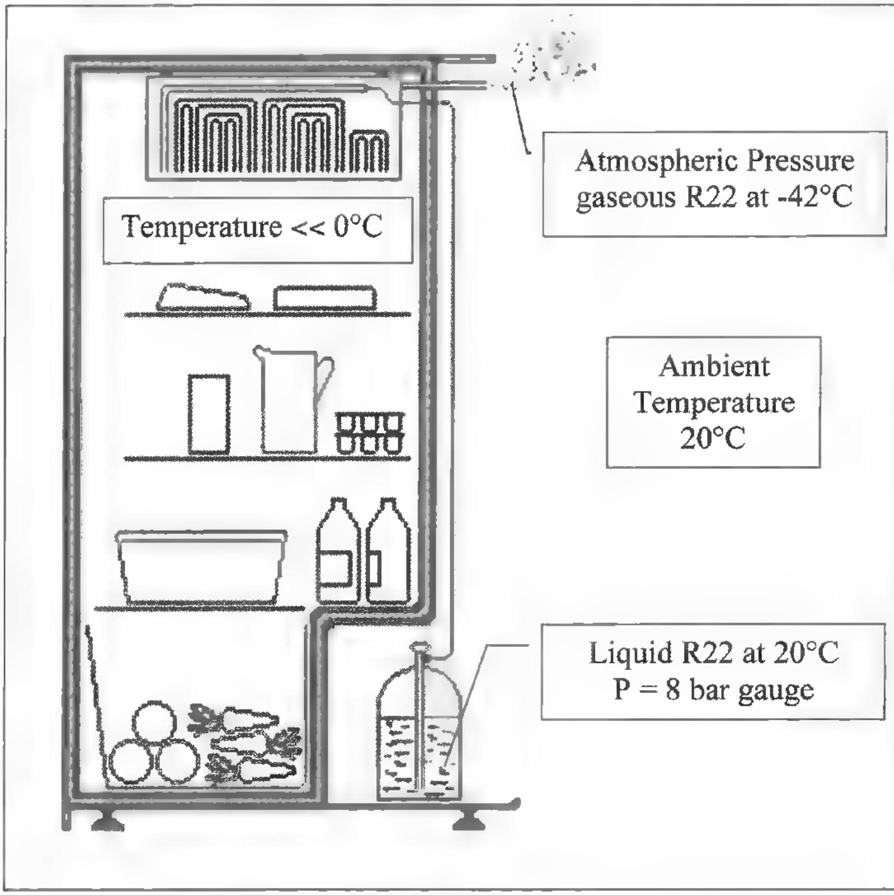
As for the water that has been placed in the ice cube tray, it has been cooled to less than 0°C and turns into ice. This is exactly what we wanted!


So all we need to do is buy a cylinder of liquid R22, connect it to our cold heat exchanger, make it leak from the outlet of our freezer, and away we go!

As R22 evaporates at -42°C at atmospheric pressure, the freezer is cooled to a temperature very close to -42°C.

At this point we could perhaps imagine an arrangement designed to cool the food in our refrigerator which is a bit more sophisticated than this...

We can construct our first refrigerator:




The R22 cylinder is placed at the rear of the equipment. A tube connects the cylinder to the cold heat exchanger whose outlet is open to the atmosphere.

As the R22 is vaporising at –42°C at atmospheric pressure, the freezer temperature becomes low enough to make ice cubes, and to chill the food stored in the fridge.

*Have you come across another name for the cold heat exchanger?*

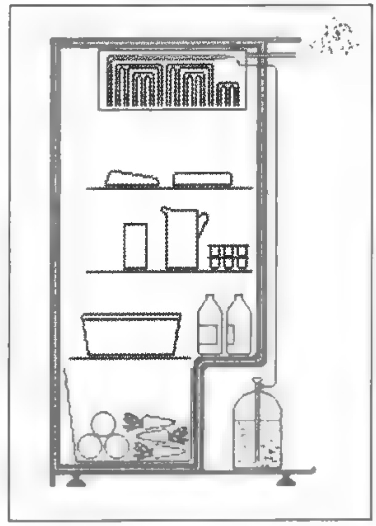
In the 'cold' heat exchanger, the refrigerant absorbs heat and evaporates. It is known to refrigeration professionals as *an evaporator.*

**The 'cold' heat exchanger where the refrigerant evaporates by absorbing heat is called the evaporator.**

Our refrigeration device appears quite interesting in principle. However, it possesses two huge inconveniences: *Can you see what they are?*

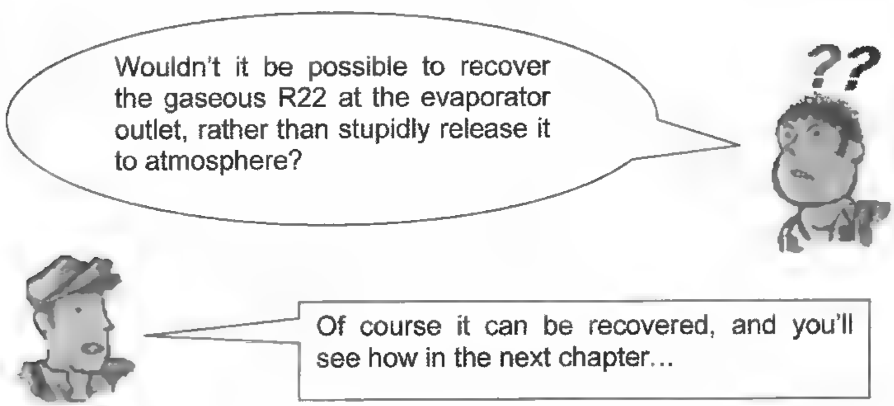
In reality, a refrigerator operating in this way possesses two major inconveniences:

1) The refrigerant we're using is constantly being lost to atmosphere. The R22 cylinder will rapidly become empty, and it will need replacing frequently: this is not at all practical, especially since R22 is so expensive (and will be more and more expensive in future!)



2) By releasing the R22 we're using to atmosphere, we are causing pollution, which is damaging to the ozone layer. This latter protects the earth from the sun's ultraviolet rays. R22 also adds to the greenhouse effect, which is causing a worrying increase in global temperatures.

So such a system as this is hardly acceptable: would you buy a highly polluting refrigerator, which needs to be "topped up" with an expensive refrigerant on a daily basis?

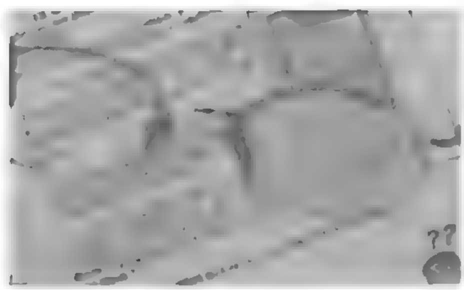


# THE PHENOMENON OF CONDENSATION

We've seen that in order to vaporise R22, that is, to change it from a liquid state into a gaseous state, all we need to do is supply it with heat. Why, then, can't we do the reverse, that is, why can't we transform gas into the liquid state?

The reverse is in fact possible, and this effect is called condensation. Before we go any further, let's remind ourselves that the air surrounding us contains water vapour. This water vapour comes from the evaporation of the sea, lakes etc., and also from our own respiration.

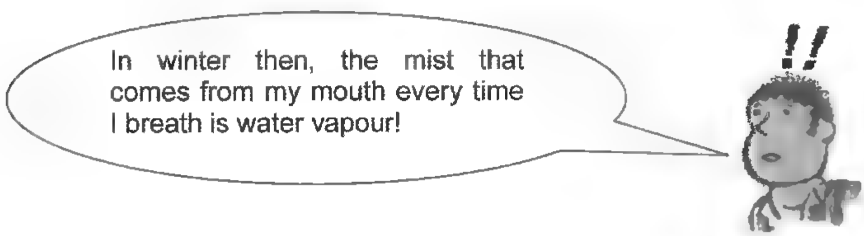
In fact, the air that we inhale picks up a good deal of water during its passage through our respiratory system.



To show this, hold a pair of glasses (or a mirror) in front of your mouth and exhale strongly.

Where does the mist that appears on the glass come from?

Note that we cannot see either the air that surrounds us or the water vapour. They are both gases that are invisible to the naked eye. Nevertheless, we can easily demonstrate the presence of water vapour in air, just by blowing on a pair of spectacles.

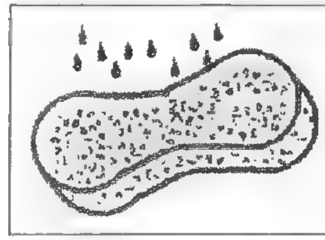



That's right, the water vapour that we exhale becomes visible when the temperature of the surrounding air is low enough. In the same way, the misting of a car's windscreen, the mist that we see on the kitchen windows in winter, the appearance of morning dew etc. are all phenomena that obey the laws of condensation.

This phenomenon of misting (condensation) occurs when water vapour comes into contact with a cold surface. For example, in the bathroom you use hot water when you use the bath or shower. The water vapour that is released greatly adds to the humidity of the surrounding air...

When the molecules of the rather warm water vapour come into contact with the colder glass of a window or mirror, they cool and misting immediately occurs.

In fact, the air is capable of holding large or small amounts of water vapour. It behaves a bit like a sponge whose capacity for absorption varies according to the how you squeeze it.



If you run a little water onto a sponge, it will be capable of absorbing it.

If, afterwards you squeeze the sponge, it releases the water as the "squeezing" reduces its absorption capacity.

Air behaves a bit like a sponge does, apart from the fact that its absorption capacity for water vapour doesn't depend on squeezing of any kind. It does however depend on its temperature: ***the hotter the air is, the more capable it is of holding water vapour; the colder it is the less it can contain.***

Why then does the mist appear when air charged with water vapour comes into contact with a sufficiently cold (glass, a windscreen or other) surface?

It's exactly the same effect that I've noticed on a glass of chilled water in the middle of summer: It gets covered with moisture!

Yes, that's exactly right. Notice that there is moisture on the outside of the glass and that the tablecloth is quite wet. Yet the glass isn't leaking! *How can we explain this?*

*Do you have any ideas?*

We can say that the air and the water vapour that it contains are cooled on contact with the cold surface. But *the colder the air is, the less water vapour it can hold:* if we cool it enough, the air will not hold any water....

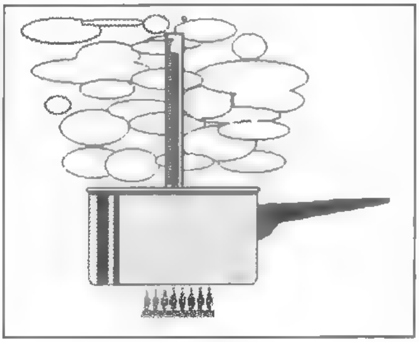
To avoid excessively scientific explanations, let's say that when the temperature of the air has fallen sufficiently, it's just like what happens when we squeeze a wet sponge hard enough.

The water vapour contained in the air starts to condense and ends up on the glass surface in the form of mist, which is nothing but a fine layer of water in the liquid state.

The state of the paper table- mat confirms this, as it is quite wet, despite the fact that the glass isn't leaking!

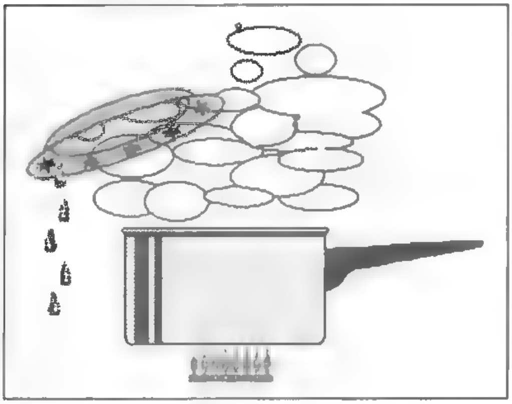
Thus, water vapour (which is a gas) changes into 'condensation' or 'mist' (which is a liquid) simply by cooling it.

We're actually seeing an example of a change of physical state: A gas changing into a liquid.



To clarify this phenomenon a bit more, we can perform an experiment.

Take a saucepan full of water and bring it to the boil. We know that after 100°C is reached, the temperature remains constant. Water vaporises by passing from the liquid state to the vapour state.



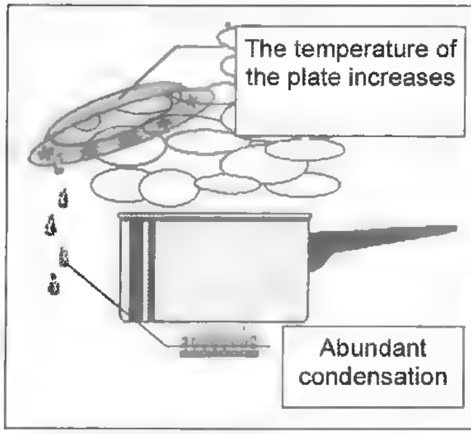
Now, if you hold a plate at a distance of about ten or so centimetres above the saucepan, what you'll observe is that the water vapour condenses freely on the plate.

Also, you'll notice that the temperature of the plate increases considerably (take care that you don't burn yourself).

*What can you say about this?*

Given that the plate is neither in contact with the saucepan or the flame, it must in fact be the vapour that supplies heat to the plate as it condenses.

Despite being very simple to perform, this experiment is nevertheless very important. It allows us to demonstrate that when water vapour is in contact with a cold surface, not only does the vapour condense, but that the cold surface becomes warmer.




**The change from the vapour state to the liquid state is known as *condensation.***

To vaporise a liquid, we must heat it. To condense a vapour, we must cool it. Really, condensation is the opposite of evaporation!

That's absolutely right. But tell me, Charlie, what type of heat does water vapour give up to the plate - sensible or latent?

The vapour condenses on the plate, so there is a change of physical state. I think that it's latent heat!

That's right, and it's called the latent heat of condensation. Of course, as with every time that we consider latent heat, the temperature remains entirely constant during the change of state.

**When a vapour condenses, it gives up heat at a constant temperature. The heat given out is known as <u>latent heat of condensation.</u>**

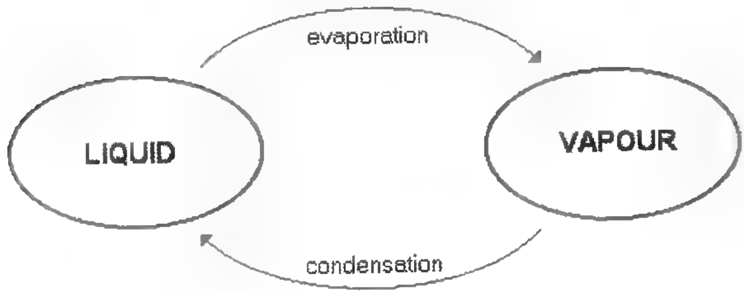
It is interesting to note that the quantity of heat given up by 1kg of water vapour during condensation is exactly equal to that needed for the vaporisation of 1kg of water.

**The phenomenon of condensation is therefore precisely the reverse of the phenomenon of evaporation.**

To remind ourselves briefly:

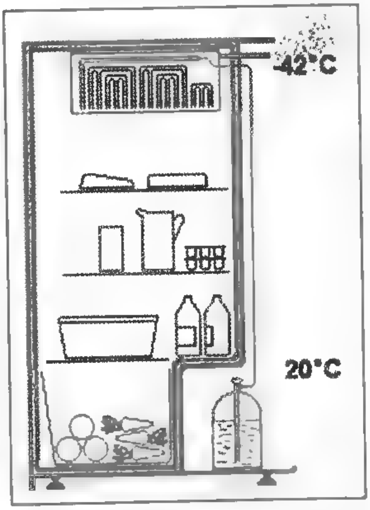
- *A liquid absorbs latent heat to allow it to vaporise and change into a gas: this is evaporation.*
- *A gas loses latent heat in order to condense and change into a liquid: this is condensation.*
- *Evaporation and condensation are changes of state that occur in a step at constant temperature.*

## ABSORPTION OF HEAT




## LOSS OF HEAT

This phenomenon of condensation can help us improve the rudimentary refrigerator seen on page 60.




If we succeed in somehow recovering the refrigerant vapour that is being released from the evaporator, and if we succeed in placing it in contact with a cold surface, it will condense, that is, it will change once more into a liquid.

So we now have a big problem: *in order to condense, gaseous R22 should be in contact with a body much colder than itself, but it's 20°C in the kitchen, and the gas at the evaporator outlet is at –42°C.*

***It seems impossible to condense R22 vapour then, unless we heat it beforehand…***

# THE ROLE OF THE COMPRESSOR

Let's think back to our old friend the 'hot' heat exchanger i.e. the black grille located behind the refrigerator (see page 5). The fact that this heat exchanger is warm means that the fluid passing though it is also warm. In fact, the function of this heat exchanger is to cool the gaseous R22 so that it condenses.

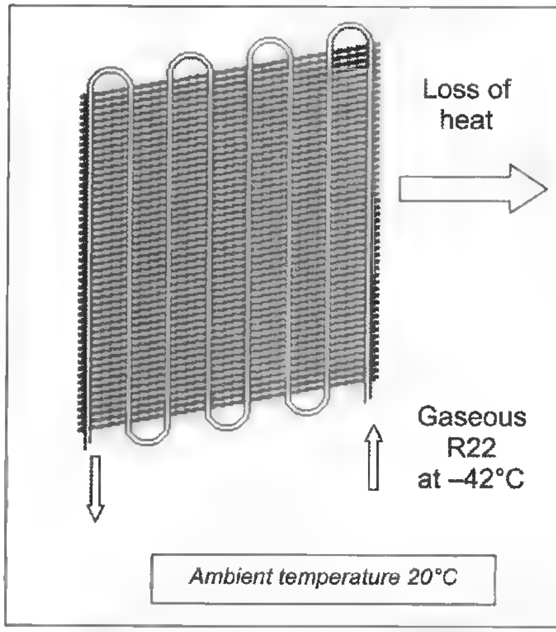
*As a reminder: the 'cold' heat exchanger in which the refrigerant evaporates is called the* ***evaporator****.*

*By analogy, the 'hot' heat exchanger in which the refrigerant gas condenses is called the* ***condenser.***

You should recall that at the outlet of the evaporator, the gaseous R22 finds itself in open air at atmospheric pressure at a temperature of -42°C.

If we had passed this vapour at -42°C directly into the condenser, *do you think cooling of the vapour would occur?*

Remember that heat passes from hotter bodies to colder bodies.




The kitchen where the fridge is found is at 20°C, a temperature which is well above that of the refrigerant. Under these conditions, how is it possible to cool vapour at –42°C with air at 20°C?

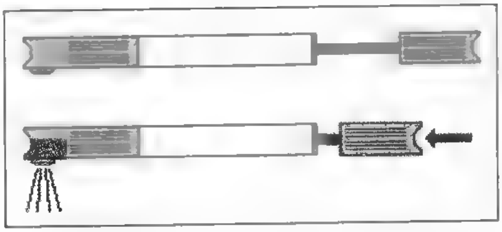
As we know, to condense the vapour, we must cool it. To condense gaseous R22 at –42°C, it is essential, then, to cool it to a temperature less than –42°C.

Now, since the kitchen temperature is 20°C, condensation turns out to be impossible. What, then, do we do next? We must either cool the kitchen to below –42°C (which would appear to be a difficult thing to do) or heat the R22 vapour to a temperature above 20°C.

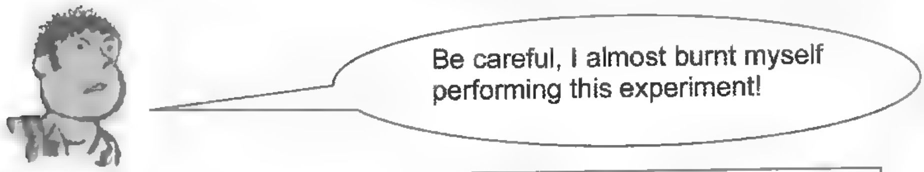
We're now confronted with a new problem. We must heat the R22 vapour that is emerging from the evaporator at -42°C before passing it into the condenser.

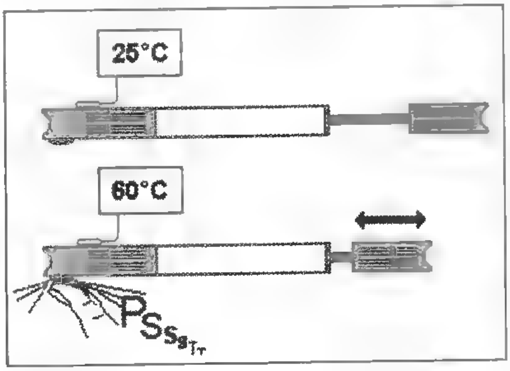
*What can we do to heat the vapour? Do you have any ideas?*

Before answering this question, and to set you on the right path, let's perform a new experiment.



Take an ordinary bicycle pump. In the first instance, operate the pump without blocking the outlet. Then pump it whilst covering the outlet with your thumb: what do you notice?



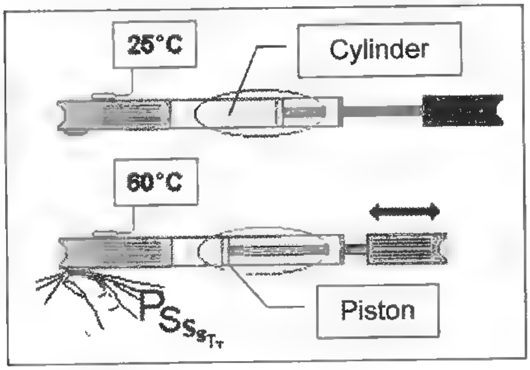




Although your thumb is blocking the outlet, the air still manages to escape.

What happens is that as soon as the pressure of the air becomes greater than that exerted by your thumb, the air can escape.

But there's another very important observation that we should make: ***the temperature of the trapped air increases noticeably***!

To obtain a better understanding of what's happening, let's take a look at the inside of this bicycle pump.




Inside the pump there is a piston which slides in the cylinder or barrel of the pump.

When the nozzle of the pump is partially obstructed the pressure in the cylinder rises, as does the temperature of the pump.

When the pressure that builds up inside the cylinder becomes great enough, the air is able to escape.

This very simple experiment demonstrates that when we compress a gas, it heats up...

Now, our problem is how to heat up the R22 vapour that emerges from the evaporator at –42°C, to a temperature that is in excess of the ambient temperature in the kitchen.

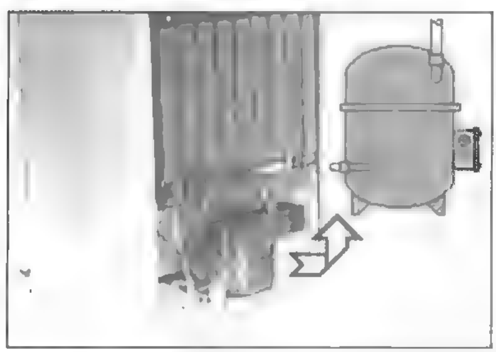
If we heat up the refrigerant vapour in this way, it would become hot enough to allow the air in the kitchen to cool the vapour. This would then allow the vapour to condense.

Here's a solution to our problem then. We need to heat the refrigerant between the outlet of the evaporator, and the entry of the condenser, so all we need to do is compress the vapour!

**Compression of a gas causes an increase in its pressure, but also an increase in its temperature.**

Naturally, we won't be using a bicycle pump in our fridge! But whilst we're on the subject, do you know where the "pump" used in a refrigeration system is found, and what its' correct name is?

The refrigeration "pump" is located at the back of the fridge, just below the condenser. It's a sort of black pot, which is completely air tight, with some tubes and electrical wires attached to it.



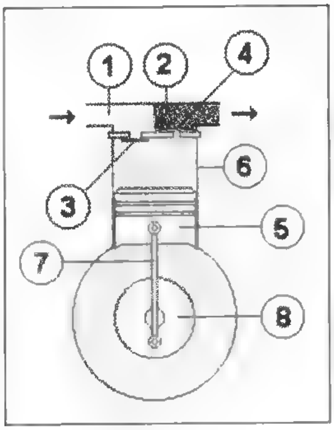
This "pump" which allows us to compress the refrigerant in the system is quite simply known as **the compressor**.

**The device that compresses the refrigerant is known as the compressor.**

Just as we observed when we examined the interior of the bicycle pump, a standard compressor is equipped with pistons and cylinders. Of course the compressor isn't driven by hand, but by means of an electric motor.

Apart from this feature, the principles of operation for such compressors are practically identical to those of a bicycle pump: The piston compressor bears a close resemblance to a motorised bicycle pump!

Just as with a bicycle pump, the function of every compressor is to take in vapour, compress it and then pump it out again at a higher temperature and pressure. Now let's examine the diagram below showing us the principles of a piston compressor.

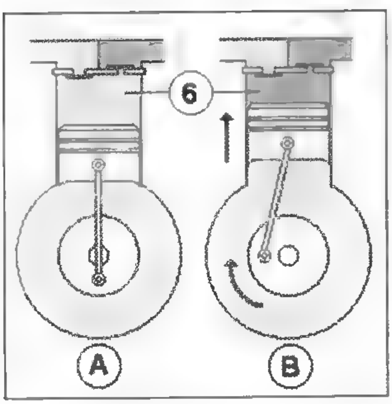



There are 2 connections to the refrigeration system. At ① we find the intake to the compressor, through which it draws in vapour to compress. After compression, the vapour is pumped out at a higher pressure through the pipework connected to ②.

As the pressure must always be higher on side ② than side ①, we talk of the Low **Pressure** (**LP**) intake or 'suction' side and the **High Pressure** (**HP**) outlet or 'discharge' side.

At ③, we find the inlet valve (which is also called the *LP valve*) and at ④ the outlet or exhaust valve (*HP valve*). These valves are actually made from small flexible strips or *reeds* of thin steel. We'll see in the next section how they operate.

At ⑤ you will recognise the piston, which slides up and down in the cylinder ⑥. The piston is connected by means of a connecting rod ⑦ to an eccentric crank ⑧. The function of this whole assembly is to convert the rotary movement of the crank into a translation or linear motion of the piston: to put it plainly, the piston should continually rise and then fall in the cylinder as the electric motor turns the crank.



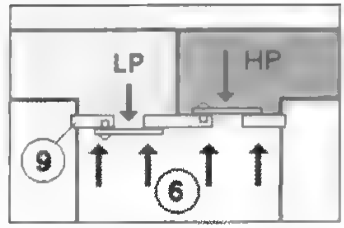

Now we'll examine what takes place in the compressor during one stroke of the piston. In order to fully understand what's happening, we'll look at each stage separately.

**Figure A.** The compressor has stopped and the piston is right at the bottom of the cylinder (this particular point, below which the piston cannot move, is called *bottom dead centre*). The cylinder ⑥ is now full of R22 vapour at low pressure (LP).

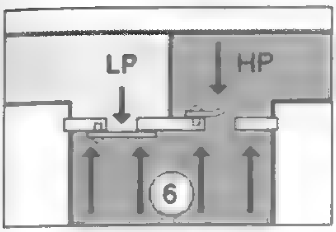
**Figure B**. The compressor is started up. The crank then starts to rotate and in turn starts to operate the connecting rod. This causes the piston to rise progressively, and as the piston rises, the pressure in the cylinder ⑥ starts to increase.

*But let's examine how the valves work…*

The valves (or *reeds*) are made up of thin strips of flexible steel, and are attached by one end to either side of a plate ⑨ located at the top of the cylinder (this plate is called the valve plate). Note that the LP and HP permanently exert pressure *on the top* of their respective valve reeds. We will see that these pressures are relatively stable.

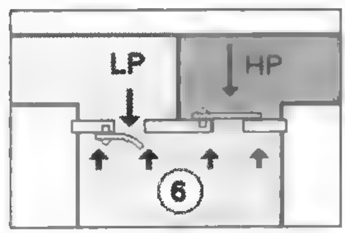



In contrast to this, the pressure that exists inside the cylinder ⑥ is exerted against *the underside* of each valve reed. Unlike the LP and HP, the pressure inside ⑥ is constantly changing, according to the position of the piston. For example, the higher the piston rises, then the more the pressure in the cylinder rises. Let's look at how the pressure that exists in the cylinder affects the position of the valve reeds.

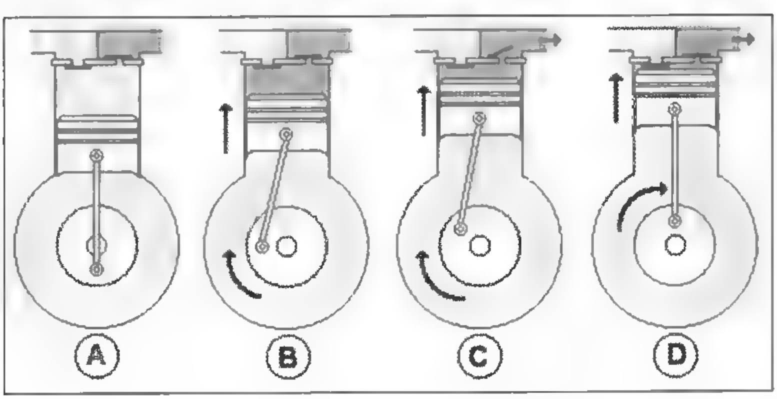



If the pressure inside the cylinder ⑥ becomes greater than the HP, the HP valve opens (in actual fact, the reed bends upwards and so allows the R22 to escape from the cylinder and leave via the HP pipework). Note that since the pressure in ⑥ is greater than the LP, the inlet valve remains closed, and effectively gas tight.

In contrast, if the pressure in the cylinder ⑥ becomes less than the LP, the LP valve reed opens (in effect, it bends downwards and so allows R22 from the LP pipework to enter the cylinder). Note that since the pressure in ⑥ is much lower than the HP, the outlet valve stays closed and gas tight.

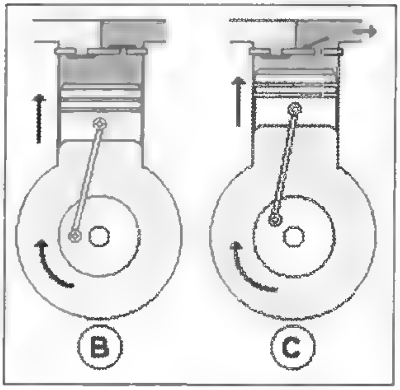



In this manner, the valve reeds can be opened or and closed in a manner that is solely dependent on the pressure that exists in the cylinder: **the valves are controlled by the refrigerant itself.**

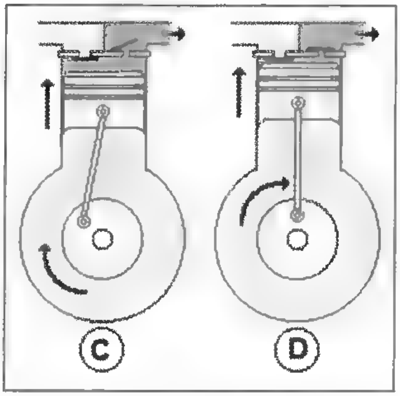



*Before continuing, try to understand the diagram above which shows the piston in different positions during its movement in the cylinder.*

From **B** to **C**, the crank continues to turn and the piston rises further and further in the cylinder whilst compressing the R22 vapour. The pressure and temperature of the gas in the cylinder increases gradually as the piston rises in the cylinder.




At **C**, when the pressure in the cylinder becomes just greater than the HP, the outlet valve reed opens, and the compressed gas is expelled into the HP pipework. Note that the LP valve is shut and gas tight whilst all this is happening.

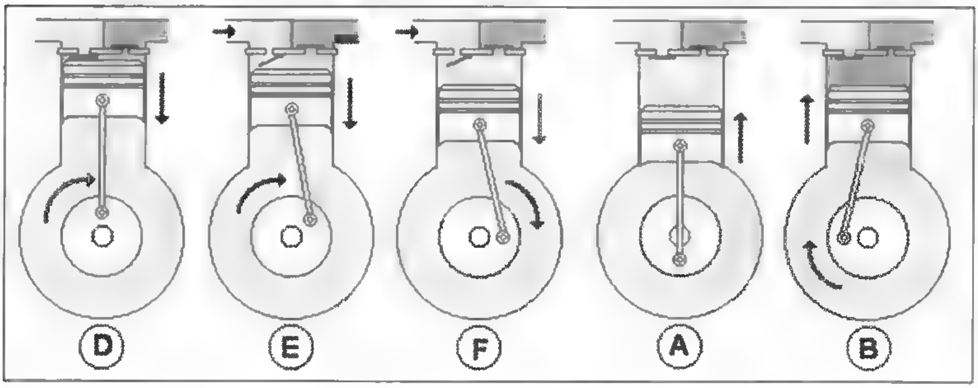



From **C** to **D**, the piston continues to expel the HP vapour, but when we get to **D**, the piston is right at the top of the cylinder. (This particular point, above which the piston cannot move, is known as *top dead centre*).

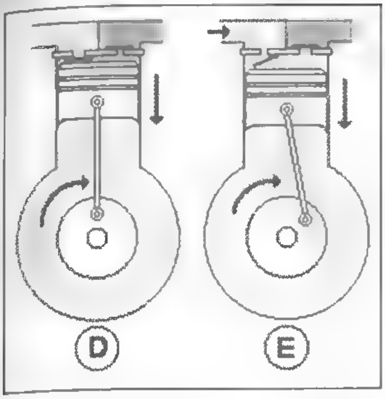
As the piston cannot rise any further, the pressure in the cylinder equilibrates with the HP and the outlet valve closes.

Note that at top dead centre, there is still a space between the piston and the valve plate. This gap, called the "dead space" or "clearance space" or "clearance volume", is essential to prevent the piston "knocking" into the valve plate. You should also note that at top dead centre, this clearance volume is still full of gas at high pressure (HP).

At **D** (top dead centre) the crank continues to rotate, and the piston starts its descent.

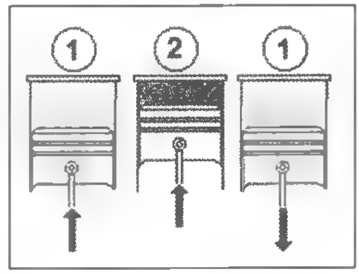



*You should now think about what's going to happen next...*



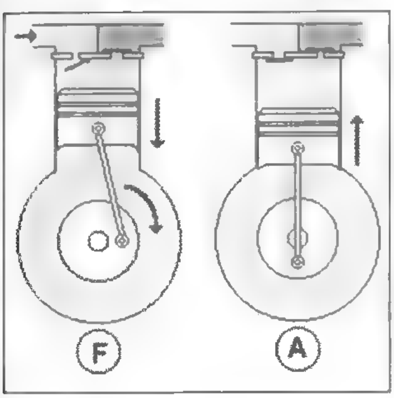

At **D**, the piston is at top dead centre, that is, it cannot move any higher in the cylinder. Both valves are closed, and some HP vapour is trapped in the clearance space. As the crank continues to turn, the piston starts to fall once again in the cylinder.

At this point, let's think for a moment: *what will happen to the pressure in the cylinder?*




Look at the diagram opposite: in ①, some gas is trapped in an enclosed space. When we move the piston up to ②, the pressure in the enclosed space increases. Now, if we bring the piston back to ①, the pressure in the closed volume returns to its initial value.

This is exactly what's happening in the cylinder of our compressor: as soon as the piston starts to move downwards, the pressure of the gas trapped in the cylinder starts to fall. Of course, as soon as the pressure in the cylinder is *just below* LP, the intake valve opens, and LP vapour is drawn into the cylinder. (Fig E).




The LP valve remains open like this during the whole of the descent of the piston (fig F).

At point (**A**) (bottom dead centre), since the piston can descend no further, the pressure in the cylinder equilibrates with the LP and the inlet valve closes.

At this point, the cylinder is completely full of LP vapour, and we have returned to our original starting point: the crank continues to rotate, the piston rises and compresses the LP vapour. It's expelled again on the HP side etc., etc.

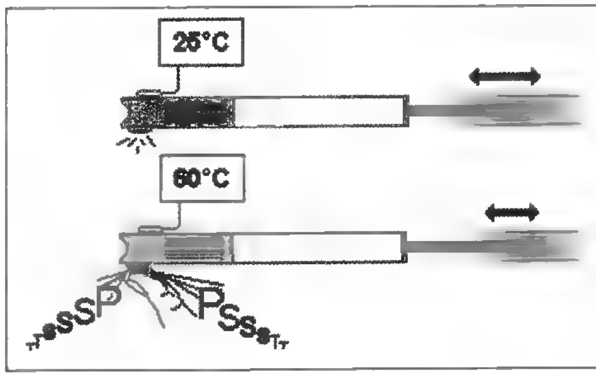
In summary, then, for each turn of the crank, the piston moves backwards and forwards once, drawing in LP vapour, and expelling it on the HP side.

For your information, many compressors have a rotation speed of 2800rpm. This means that the piston rises and then descends 2800 times per minute, that is, close to 47 times per second. This also means that each HP and LP valve reed opens and closes nearly 47 times per second!

# THE ROLE OF THE EXPANSION DEVICE

In our bicycle pump experiment, you will recall that the air is heated as it escapes from the piston past your thumb, which is partially blocking the outlet.

If you lift your thumb, the air is compressed much less, and the temperature drops. You can then operate the pump with little difficulty, as the air being pumped out is at low pressure.




The converse is also true. The more you block the outlet with your thumb, the more you will notice the rise in temperature, and that it becomes more and more difficult to operate the pump.

**In effect, the more you obstruct the outlet orifice, the more the pressure increases and the temperature rises.**

We can say that the outlet temperature rises when pressure of the gas rises!

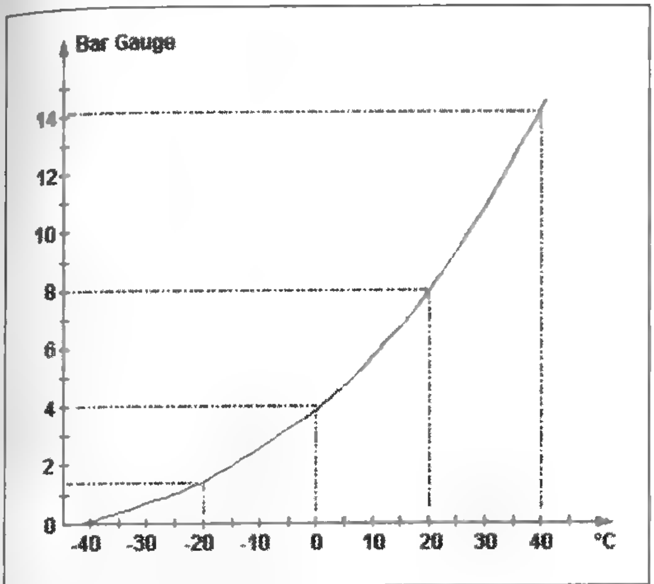
That's right, and it's exactly the same for a fridge compressor: the higher the pressure becomes, the greater will be the temperature of the gas it pumps out.

Do you remember that in the last chapter we saw that the condensation of R22 vapour was only possible if the temperature of the vapour was greater than that of the kitchen?

So with an ambient temperature of 20°C in the kitchen we must raise the temperature of the R22 to something greater than 20°C.

*Do you have any ideas about how we move on from here?*

## THE PRESSURE- TEMPERATURE RELATIONSHIP OF R22




The pressure-temperature relationship for R22 shows us that at 20°C, *the condensation* (or the evaporation step, since this is the reverse phenomenon) occurs at a pressure of about 8 bar.

**We can conclude that in order to condense R22 vapour emerging from the evaporator at –42°C with the surrounding air at 20°C, *we must not only increase the temperature of the vapour to above 20°C but also increase its pressure to something over 8 bar.***

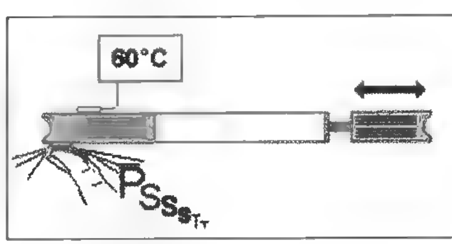
*This is excellent, as it is precisely what the compressor does. By compressing the vapour it simultaneously raises its pressure and its temperature!*

The greater that the outlet pressure of the compressor is, the higher the temperature of the R22 vapour will be, and the easier it will be to cool and to condense.

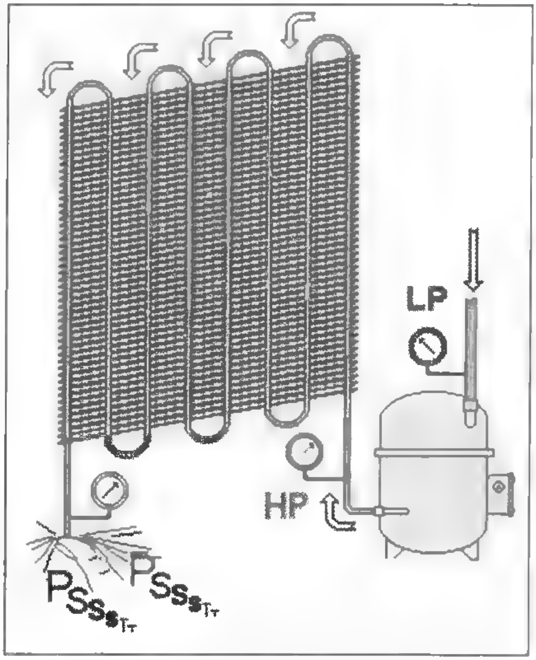
Our problem, then, boils down to increasing the pressure and the temperature of R22 vapour entering the condenser, so that we can easily condense it.

Remember that in the bicycle pump the more the outlet is blocked, the higher the resulting pressure and temperature is.

The air emerging from the pump is very hot, and can only get colder.




*So how are we going to proceed with our refrigeration system?*



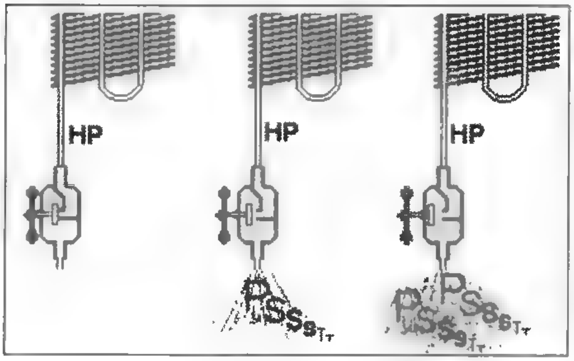

If we want to cool gaseous R22 to make it condense, we must increase its temperature and pressure inside the condenser.

Still using the example of the bicycle pump, the "thumb" that partially obstructs the system will be placed at the outlet of the condenser.

In this way, the refrigerant that is drawn in from **LP**, then compressed by the compressor will be pumped out at **HP** and maintained at high pressure in the condenser because of the thumb that partially obstructs the its outlet.

Since the refrigerant is at HP in the condenser (well above 8 bar), its temperature will be in excess of 20°C. The air at 20°C in the kitchen will therefore easily be able to cool the hot R22 vapour, and allow it to condense.

As the R22 vapour is being condensed, liquid R22 will emerge from the condenser. But you may recall that liquid R22 vaporises at –42°C at atmospheric pressure. It's fairly obvious that something other than a thumb must be used to make a partial obstruction at the outlet of the condenser, or we'll risk burning ourselves quite badly!




Instead of our thumb at the condenser outlet, let's install, for example, a valve that we can open to varying degrees.

**This valve allows liquid refrigerant to pass from a high HP pressure value to a much lower LP pressure** (in our example, the pressure at the outlet of the valve is equal to atmospheric): It causes a large drop in pressure.

In the jargon used by refrigeration professionals, we say that a fluid that experiences a large drop in pressure undergoes an **expansion.** *In your opinion, then, what should fridge engineers call this valve?*

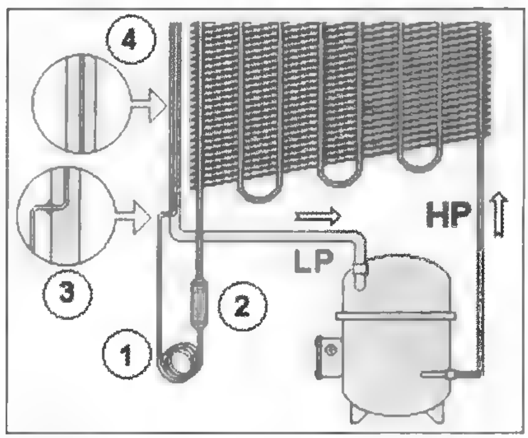
This device that causes an expansion (a large drop in pressure) is quite naturally called an "expansion valve".

**The device that causes a large drop in pressure (from HP to LP) is called *an expansion valve*.**

Our valve here functions as a manually controlled expansion device. Such expansion devices are rarely used nowadays, and there exist numerous other types of fully automatic expansion devices. For example, the device used in a refrigerator isn't actually a valve: *do you know whereabouts in your fridge it is found?*

Whatever technology is used, the expansion 'valve' is situated somewhere along the tube that emerges from the condenser. In small, highly mass-produced equipment (refrigerators, air- conditioners etc.), the market is highly competitive, and the price of equipment is a critical feature. That is why, for reasons of economy, manufacturers install expansion devices with the lowest possible cost. These are usually constructed from a length of copper tube of very small diameter, through which liquid refrigerant flows with difficulty. This causes a "hold up" just as our thumb did earlier.

This very narrow tube (ref **1**) is also called a "capillary" or "capillary expansion device".



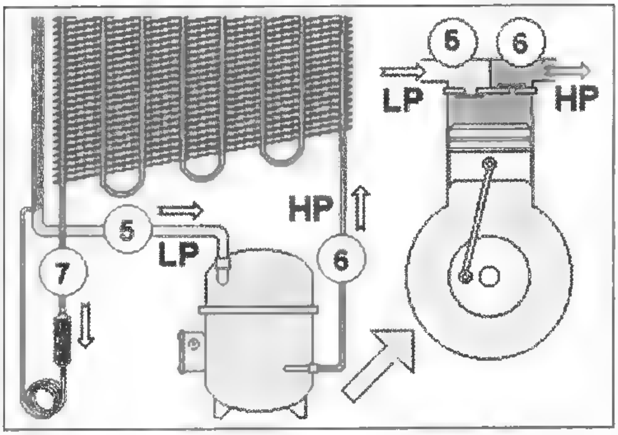

At the condenser outlet, you should also have been able to see the filter (ref **2**). Its role is to trap any possible impurities (such as copper turnings, bits of abrasive or brazing materials) which could block the very fine interior diameter of the capillary expansion device.

The other point of interest is that the capillary tube passes inside the compressor inlet pipework. The integrity of the capillary's point of entry is assured by brazing the access point (ref **3**). Note that the refrigerant flows independently in each of the two tubes (ref **4**) and no mixing is possible. This feature is simply a technical option taken by the manufacturer.

But before continuing with the capillary expansion 'valve', look closely at the above diagram, and think about these two questions: *what is the physical state (vapour or liquid) and the pressure (LP or HP) of the refrigerant:*

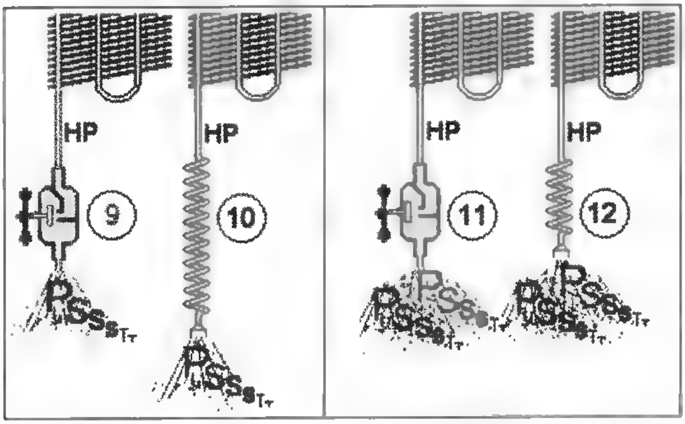
1. *At the condenser inlet?*
2. *At the inlet to the capillary?*

We've seen in the previous chapter that the LP vapour is drawn in by the compressor (see ref. **5**), and after being compressed in the cylinder, is then expelled towards the condenser (see ref. **6**). *We can conclude then that this is very hot HP vapour that emerges from the compressor and enters the condenser.*




Since the R22 vapour is much hotter than the surrounding air, it condenses by giving up heat to the air in the kitchen. *We will find high pressure R22 liquid at the outlet of the condenser, and of course, at the inlet to the capillary (ref. **7**).*

Now we can improve our knowledge of the capillary expansion device a little. It's true to say that this is the type of expansion device that we'll come across most often in our small refrigeration systems. Although it is very simple technology (it is simply a length of tubing of small diameter), the action of the capillary is the same as that of the valve seen earlier: *It creates a resistance, or opposition, to the flow of the refrigerant.*

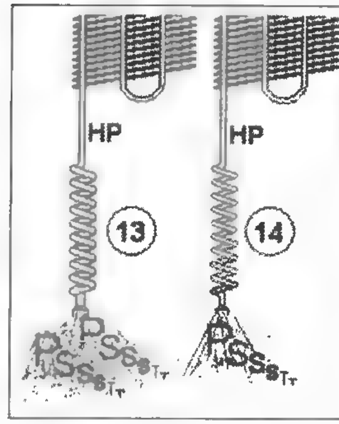



In the case of the valve, this resistance depends on the degree to which it is opened. If it's almost closed, the valve will only allow minimum flow (ref. **9**). When fully open, the valve allows maximum flow (ref. **11**). The flow is therefore a function of the degree of opening, that is, of the resistance of the valve to the refrigerant flow.

In contrast, the resistance of the capillary depends on its length. A fairly long capillary (ref. **10**) provides a high degree of resistance to the refrigerant flow, just like a nearly closed valve. If we shorten the capillary (ref. **12**), its resistance decreases: the refrigerant can then flow easily, just as it would through a fully opened valve.

*But can you see anything else that could affect the resistance of a capillary?*

Another very important influence on the resistance of the capillary is the interior diameter of the tube. Here, the capillary in ref. **13** has a larger diameter than the capillary in ref. **14**. *Although both capillaries are of exactly the same length,* the flow through 13 (large diameter) is much greater than the flow through 14 (small diameter).




Thus, the smaller that the internal diameter of the capillary tube is, the greater is the resistance to the passage of refrigerant, and the smaller is the flow.

In summary, the resistance of the capillary depends on its length and its diameter. Once installed, the dimensions of the capillary won't change and the resistance to flow is fixed.

In effect, a capillary is like a valve stuck in a position defined by the manufacturer!

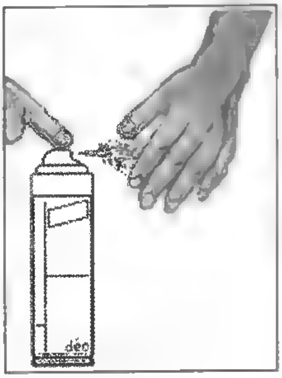
That's quite right, but never forgets that a capillary expansion device is a valve that's *absolutely* stuck. It's specified *once and for all* by the manufacturer depending on the cooling capacity, the quantity of refrigerant in the equipment, the designed operating conditions etc.
If any one of these values changes, the capillary won't give the required performance. In effect, the capillary acts as a 'frontier' between HP and LP: This is a very important piece of equipment!

***The expansion device is a sort of frontier between HP and LP. Without an expansion device there can be no compression, no heating, no condensation, no liquid refrigerant, and so no evaporation.***

***No expansion device, no refrigeration cycle!***

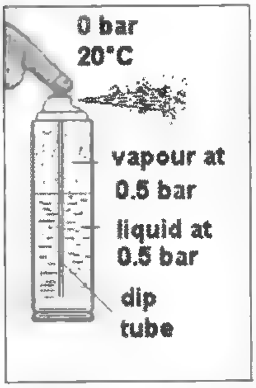
Now that you know that we have liquid refrigerant arriving at the inlet to the expansion device, *we'll try to find out exactly what physical state the refrigerant is in at its outlet…*

So that we can obtain a better understanding of what happens at the expansion device, we'll perform an extremely simple experiment together:




a) Take a can of hair spray or pressurised aerosol deodorant. Shake it whilst listening carefully to the noise it makes inside, and then try to estimate its temperature.
b) Now press the spray head and send a jet of product onto the inside of your other hand. Look at what's on your hand and wait for a short while.
c) What sensation could you feel on the palm of your hand: cold or heat? *What can you conclude from this?*

Inside a can like this, there is a mixture of liquid and vapour (you can tell that this is so from the noise that is heard from the inside of the can when you shake it)




When you hold the can in your hand, you can feel that it is at ambient temperature, that is, at about twenty degrees. Let's say that at 20°C the pressure inside the can is, for example, 0.5 bar. That is, slightly more than atmospheric pressure (which, you will remember, corresponds to 0 bar).

Then, when you press the spray, some product is expelled from the can. This proves that the pressure inside the can is actually greater than atmospheric pressure. Furthermore, you observe that the product is liquid, and so this must be at the bottom of the can, and that therefore the can must be equipped with a dip tube.

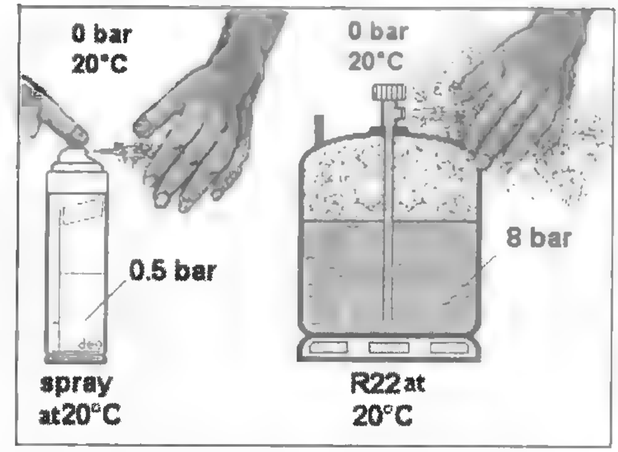
What do you observe when you spray a little of the product onto the palm of your hand: Firstly, you can distinctly see that it's in the form of a liquid. At this point, after waiting a little while whilst observing carefully what happens to the liquid in your hand, you observe that the liquid is gradually disappearing, and that simultaneously you can feel a cooling sensation on the palm of your hand. *What is happening*?

As it passes through the small orifice of the spray, the pressure of the liquid falls from 0.5 bar (inside the can) to atmospheric pressure (that is, 0 bar).

But do you remember that a device which causes an expansion (that is a fall in pressure) is called an expansion device? The spray head of the aerosol can acts, then, like a mini expansion device.

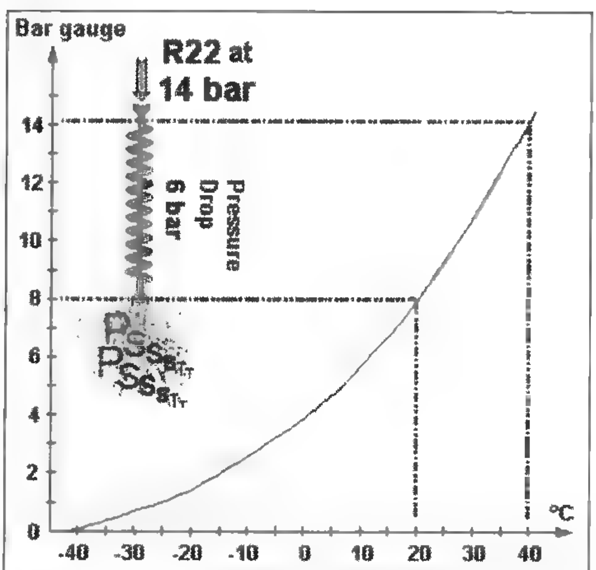
*Are you starting to understand the cooling sensation that you felt?*

**Let's remind ourselves:** when R22 at 20°C and at 8 bar pressure was released from a cylinder, it expanded until it was at atmospheric pressure (the surroundings were at 20°C and 0 bar). The liquid vaporised by absorbing heat from the surrounding air and from your hand. Remember that liquid R22 vaporises at –42°C at atmospheric pressure, and that you risked a severe burn.



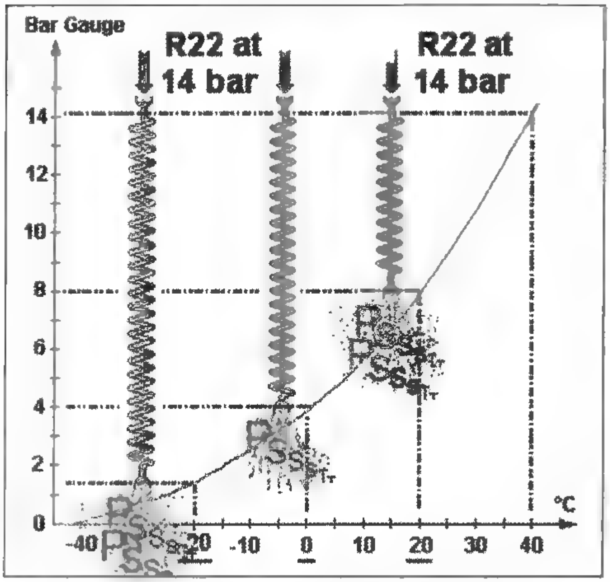

As it emerged from the aerosol can, the liquid at 20°C and 0.5 bar expanded until it was at atmospheric pressure (the surroundings were at 20°C and 0 bar) exactly as the R22 did (but fortunately manufacturers put liquids into their sprays that vaporise well above 0°C !!). However, in order to evaporate, all liquids must absorb heat from somewhere. This is why you feel a cooling sensation on the palm of your hand as the liquid gradually absorbs heat from it in order to vaporise and dissipate into the atmosphere.

In these two examples, the spray head of the aerosol can, like the valve of the R22 cylinder, acted as an expansion device. By creating a pressure drop (of 0.5 bar for the aerosol and of 8 bar for the cylinder valve), they caused the evaporation of the liquid. In our refrigeration system, this role of expansion device falls to the capillary. We know that the resistance of the capillary depends on its length and on its diameter.




Assuming that the R22 liquid emerging from the condenser (that is at HP) arrives at the inlet to the capillary at 14 bar, this would correspond to a condensation temperature of 40°C, as is shown by the pressure- temperature curve for R22.

If the capillary has been chosen to create a pressure drop of 6 bar, the liquid at its outlet will be at 8 bar and will vaporise at 20°C: *do you think that this will be sufficient to chill our foodstuffs?*

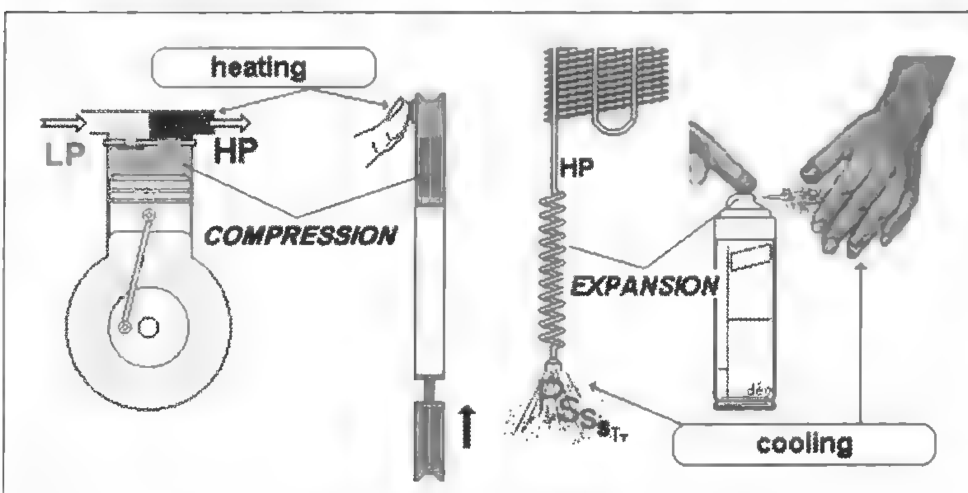


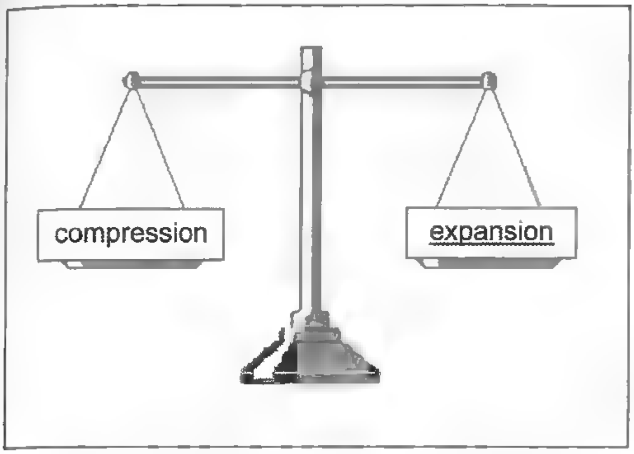

On the other hand, if a manufacturer has chosen a longer capillary, which creates a pressure drop of 10 bar (instead of the previous 6 bar), the liquid will be at 4 bar at the outlet. As the pressure-temperature relationship for R22 shows, the liquid will then vaporise at 0°C, which already would seem more satisfactory for chilling our food.

Note that if the capillary expansion device is longer still (or of still smaller diameter), the pressure drop will be even larger, and the evaporation temperature even lower. Thus, if we want the liquid to evaporate at –20°C (which corresponds to a pressure of 1.5 bar) all we need do is select a capillary that generates a pressure drop of 14 -1.5 = 12.5 bar.

**Thus, depending on the operating conditions required, and the type of equipment (fridge, air conditioner...), the manufacturer can determine in advance the pressure drop that a capillary must generate.**

So, we've seen that the compression of a gas has the effect of increasing its pressure and temperature. In contrast, the expansion of a liquid has the effect of reducing its pressure and temperature.






In fact, expansion produces exactly the opposite effects to compression:

**Compression = Increases in pressure and temperature.**

**Expansion = decreases in pressure and temperature.**


## Let's summarise:

*We've now covered some of the operating principles of refrigeration systems. Before we continue, let's do some revision of the principal rules we should remember. If you have any doubts about any of these rules, revise the appropriate chapter before continuing.*

- ***There can only be a transfer of heat between two bodies if those two bodies are at different temperatures.***

- ***Heat always flows from a hotter body to a colder one.***

- ***The change from the liquid state to the vapour state is called vaporisation.***

- ***When a liquid evaporates, it absorbs heat, but its temperature remains constant. The heat absorbed by the liquid in this way is called the latent heat of vaporisation.***

- ***The evaporation temperature and the evaporation pressure always vary in the same direction. They increase or diminish together. They are linked.***

- ***The 'cold' heat exchanger where the refrigerant vaporises by absorbing heat is called the evaporator.***

- ***The change from the vapour state to the liquid state is called condensation.***

✎ ***As a vapour condenses, it gives out heat at a constant temperature. The heat that is given out is called the latent heat of condensation.***

✎ ***The heat exchanger where the refrigerant condenses is called the condenser. It is this heat exchanger that gives out heat.***

✎ ***Compression of a gas has the effect of increasing its pressure and its temperature.***

✎ ***The item of equipment that allows us to compress a refrigerant is called the compressor.***

✎ ***The device that causes a large pressure drop (the change from HP to LP) is called an expansion device.***

✎ ***The expansion device is a sort of frontier between HP and LP. Without an expansion device, there can be no compression, no heating, no condensation, no liquid refrigerant and so no evaporation. No expansion device, no refrigeration system!***

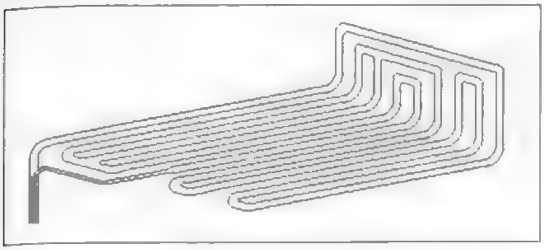
If you want to really understand what is to follow, and in particular how an air- conditioner works, so that you can install it correctly and complete simple repairs, it is essential that you understand these rules perfectly.

Sure, I realise that without some effort on my part, I won't be able to make any progress!

*At the risk of being repetitive, if you have any doubts about any of these rules, then it is much better to re- read the appropriate chapter before continuing.*

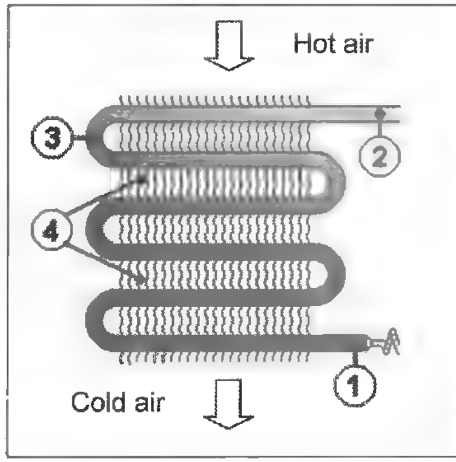
# THE REFRIGERATION CYCLE

## The Evaporator:



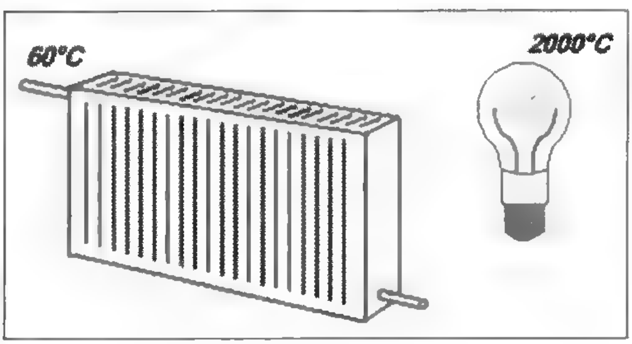
As its name indicates, it's in the evaporator that the refrigerant evaporates: it changes from the liquid state to the vapour state *and absorbs heat as it does so.* This causes the food placed in the fridge to be chilled.

In order to simplify our explanations, we'll represent the evaporator using the figure opposite.




In the diagram we can observe the inlet (**1**) and the outlet (**2**) of the evaporator. The refrigerant flows in the refrigerant tube (**3**). The thin metal fins (**4**) improve the heat exchange between the fluid flowing in the tube, and the air that passes over the evaporator.

*So, do you know what the fins do, exactly?*



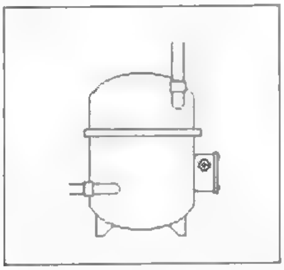

If you examine the radiator and the light bulb opposite, they should give you an idea.

The filament of the light bulb at 2000°C won't heat up a room, but a radiator at 60°C will heat it adequately, simply because its exchange surface in contact with the air around it is so much larger!

So, the larger the heat exchange surface that is available, the more efficient a heat exchanger is. As they actually increase the exchange surface area, the fins allow an improved exchange of heat. Their role is vitally important, and they should always be kept clean and in good condition.

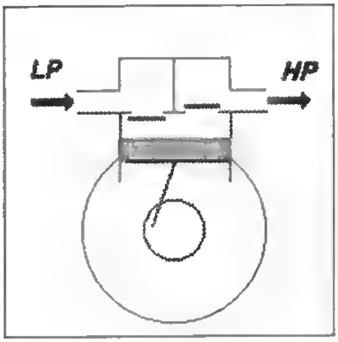
*So, now do you understand the role of the fins?*

## The compressor:



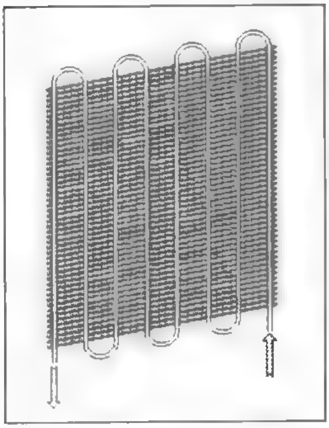
At the evaporator outlet, the refrigerant in the vapour state at low pressure (LP) is drawn in by the compressor, and is compressed to a high pressure (HP). The effect of this compression is to simultaneously increase the temperature and pressure of the vapour that is discharged towards the condenser.

The refrigerant enters the compressor at LP as a "cold" vapour, and emerges as a "hot" vapour.




To make our explanations clearer, we'll represent the compressor using the diagram opposite.

## The condenser:

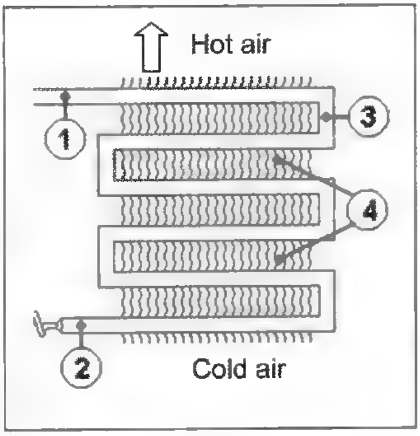


The refrigerant emerging from the compressor is much hotter than the ambient temperature of the kitchen.

It is cooled in the condenser, and passes from the gaseous state to the liquid state, giving out heat as it does so.

Heat transfer always takes place from the hotter body to the colder, that is, from the refrigerant to the air of the kitchen.

The condenser's role is to facilitate this thermal exchange.

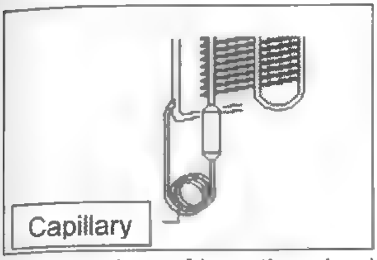



To simplify our diagrams and to make explanations easier, we'll represent the condenser by the figure opposite.

In this diagram we observe the inlet, (**1**) and the outlet (**2**) of the condenser. Refrigerant flows through the refrigerant tubing (**3**) whilst changing from the gaseous state to the liquid state. The fins (**4**) facilitate the thermal exchange between the refrigerant and the air, exactly as in the evaporator.

The only differences between the diagram for the condenser and that of the evaporator are the ends of the tubing. So, to avoid confusion, we draw the condenser with rectangular ends, and the evaporator with circular ends.

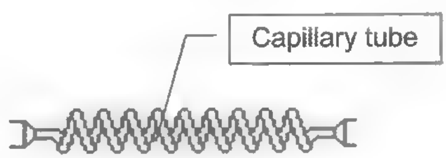
**The Expansion Device:**




The expansion device connects the condenser outlet to the evaporator inlet. It carries out the expansion of "hot" liquid at high pressure, so that it becomes "cold" liquid at low pressure.

Despite its small size, it is actually one of the four essential elements of the compression refrigeration circuit.

To simplify our diagrams and to make explanations easier, we will use the symbol for the expansion device shown here.




The capillary expansion device is made up of a single long, thin copper tube. Refrigerant may flow through it in both directions, but its interior diameter and length are fixed, otherwise the quantity of the refrigerant entering the evaporator will be incorrect.

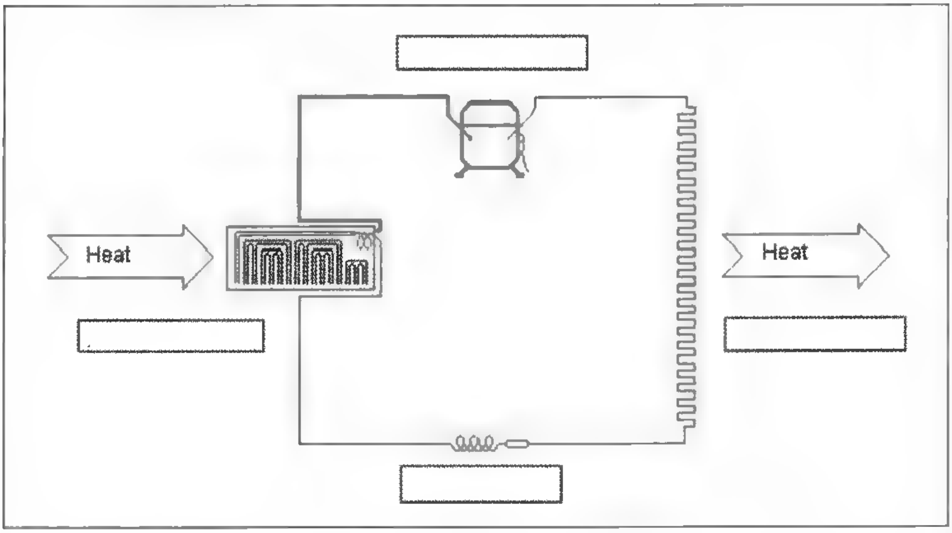
The expansion device, the evaporator, the compressor and the condenser are the four indispensable elements of a refrigerant circuit. If only one of them is missing or defective, the system won't work properly. It's vital, then, that we completely understand the role, the operation and the graphical representations of each of these items.

So I need to be capable of recognising and understanding the operation of these four principal elements from a refrigeration system diagram.

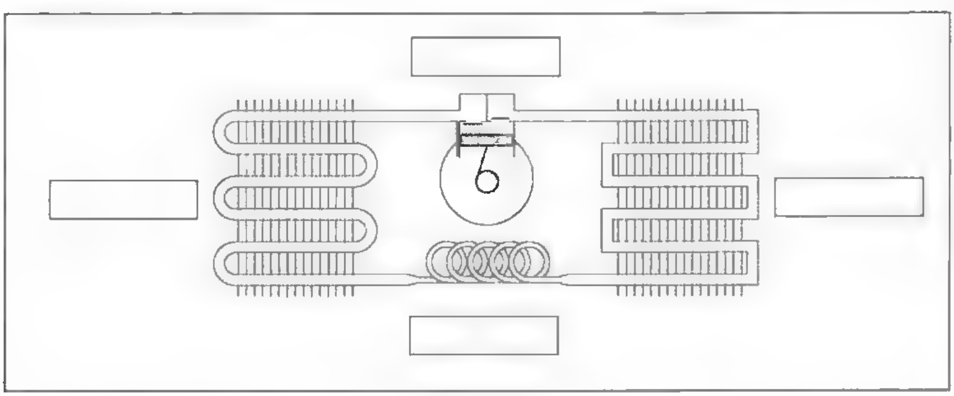
## The Refrigeration Circuit:

To bring this chapter to a close, try and complete the outline sketches below by naming the devices and showing the direction of flow of the refrigerant:

### 1) For a refrigerator:

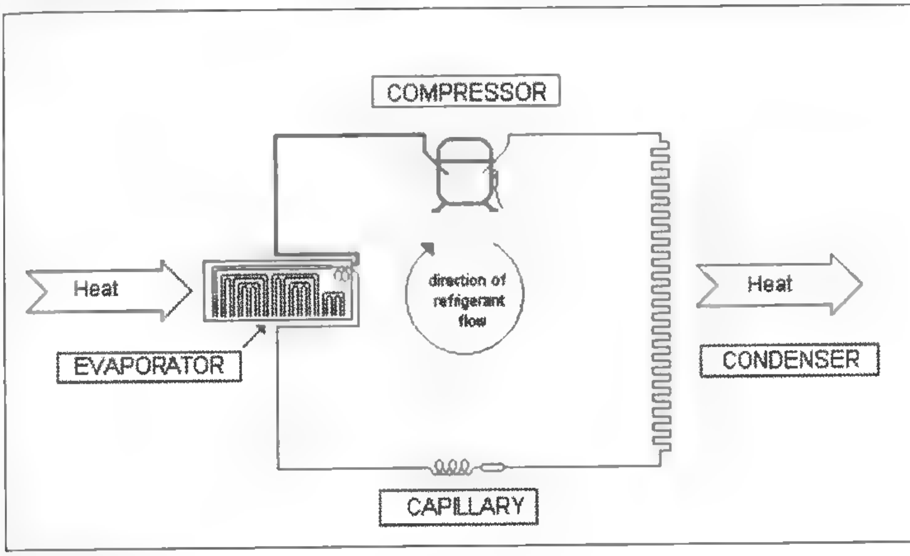



### 2) In General:

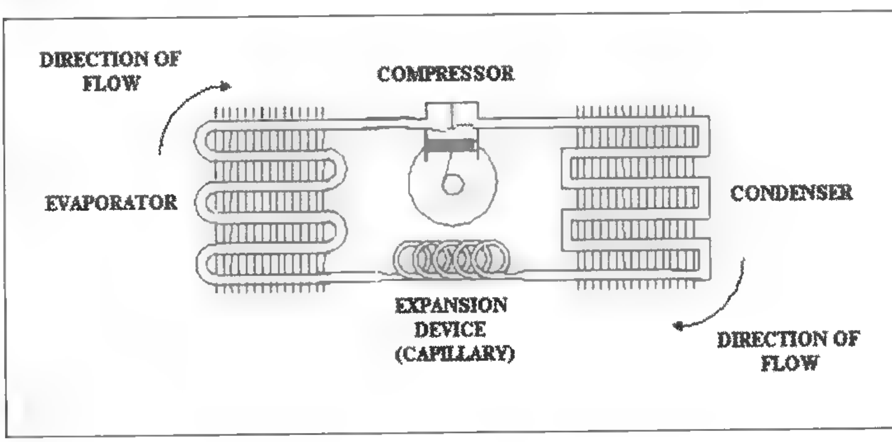


## Solution:

1) *In a refrigerator:*

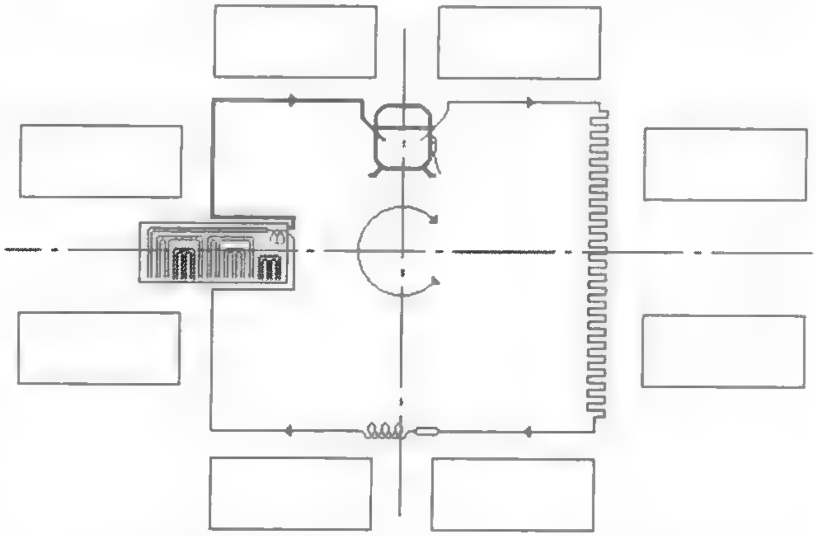



2) *In general:*

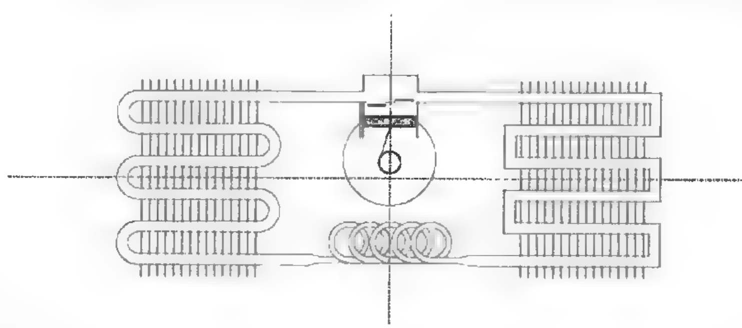



It is important to be able to recognise the essential features of a refrigeration system (e.g. the direction of refrigerant flow, the state of the refrigerant at any point - LP, HP, vapour, liquid - and of course the function of each device) just by looking at a diagram like this.

Now, we're going to separate the system into four pieces, and you can try and place the various text items given in their correct places...



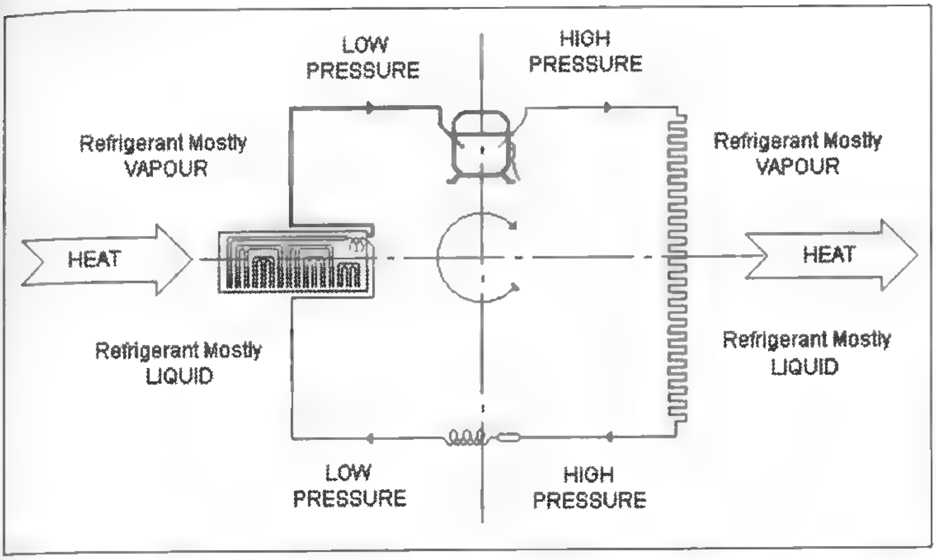
| | | | |
|---|---|---|---|
| Refrigerant Mostly LIQUID | HIGH PRESSURE | Refrigerant Mostly VAPOUR | LOW PRESSURE |
| Refrigerant Mostly LIQUID | HIGH PRESSURE | Refrigerant Mostly VAPOUR | LOW PRESSURE |



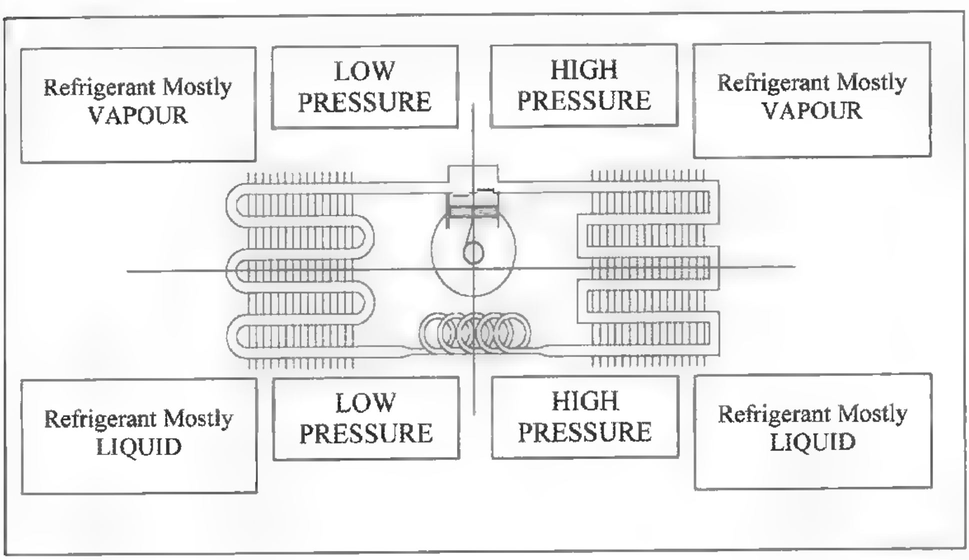
| | | | |
|---|---|---|---|
| Refrigerant Mostly LIQUID | HIGH PRESSURE | LOW PRESSURE | Refrigerant Mostly VAPOUR |
| Refrigerant Mostly LIQUID | HIGH PRESSURE | LOW PRESSURE | Refrigerant Mostly VAPOUR |

**Solution:**

1) *In a Refrigerator:*



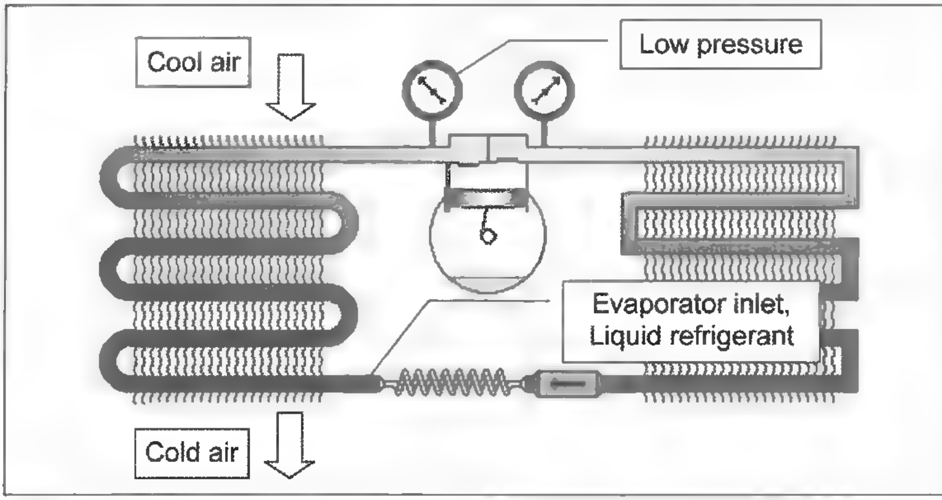

2) *In general:*




You should try and understand these concepts properly in order to get full benefit from what follows...

## Operation:

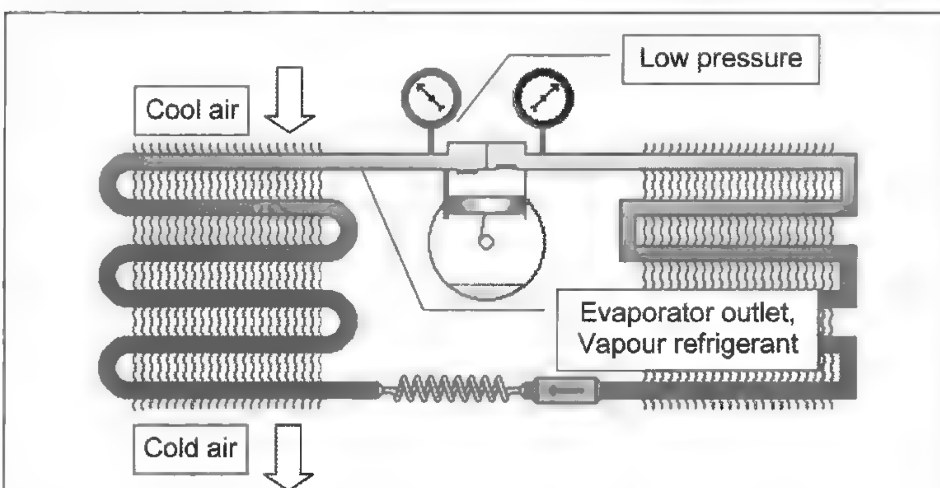
The R22 emerging from the capillary enters the evaporator in the liquid state, and at low pressure (LP). Its temperature is much lower than that inside the fridge.



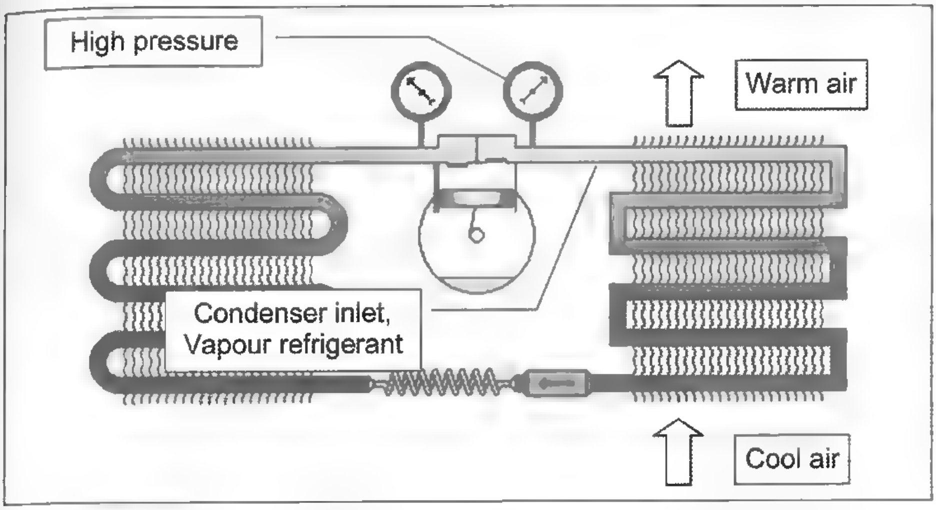

When two bodies are at different temperatures, heat always flows from the hotter body to the colder one. There is therefore a transfer of heat between the foodstuffs and the R22.

The R22 absorbs heat from the food, and this heat causes it to vaporise (this is the latent heat of evaporation). This is why the R22 evaporates, and simultaneously cools the interior of the refrigerator.

At the evaporator outlet, the R22 in the vapour state and at low pressure is drawn in by the compressor. Compression then simultaneously increases the pressure and the temperature of the vapour.

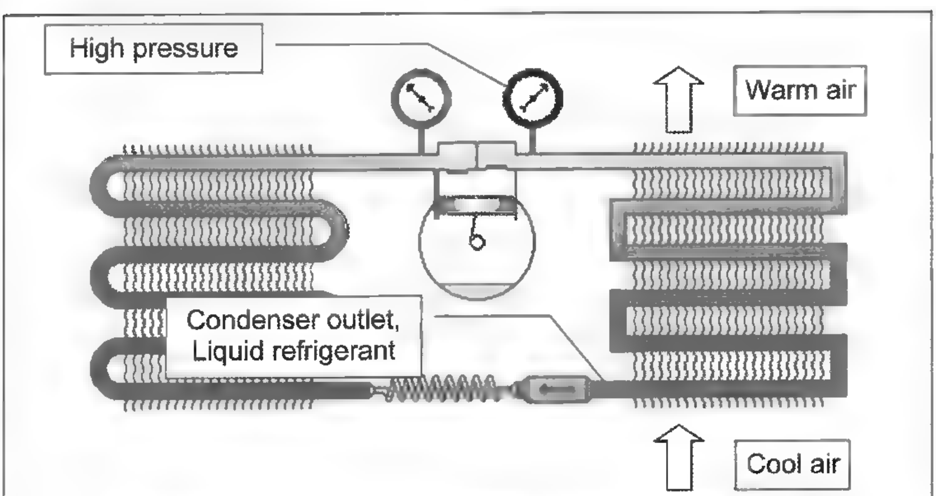


The R22 vapour at high pressure (HP) and at high temperature then enters the condenser. Heat flows from the hotter body to the cooler body, and the R22 gives up its heat to the air in the kitchen (which is warmed by this action).




As the R22 loses heat, it condenses (and gives up latent heat of condensation).

At the condenser outlet, the R22 is in the liquid state at high pressure. It then passes through the capillary and is expanded to low pressure and low temperature: *We've now come back to our starting point.*



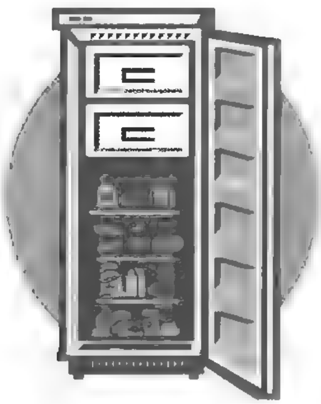

Each time it completes this circuit, the R22 passes through exactly the same points, in the same physical state, and with the same properties, and is never consumed...

This is why some refrigerators can operate for more than thirty years, without any maintenance of their refrigeration system.

## Conclusion:

A refrigerator is equipped with an evaporator in which the refrigerant absorbs heat as it changes from the liquid state to the vapour state. At the same time, the enclosed space inside the fridge is cooled.

The heat absorbed is then given up by the condenser into the surrounding air of the kitchen, which has the effect of causing the refrigerant to condense.



The refrigeration circuit, therefore, pumps heat from the interior of the fridge and emits it to the exterior.

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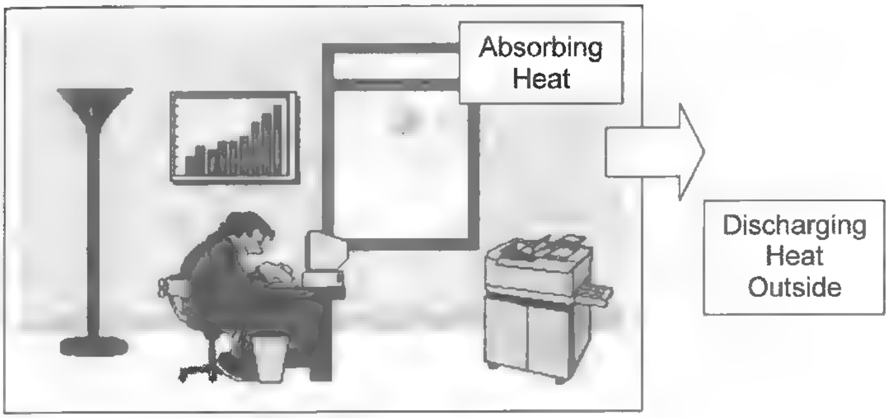
*If some of what has gone before seems a bit unclear to you, don't hesitate to do some revision on it. When you feel that you understand this first part completely, we can pursue our studies of refrigeration systems in a little more depth…*

# FROM THE FRIDGE TO AIR CONDITIONNING

The principal role of air conditioning is to maintain a comfortable temperature in a room by counteracting the heat produced by people, lighting, the sun, machines etc.




A pleasant temperature means increased numbers of customers in shops, improved productivity in offices etc.

But please note that if you think that air conditioning in your bedroom is a good idea, then you should know that rabbit breeders use air conditioning to improve the reproduction of their stock!

The role of air conditioning is really to provide comfortable conditions, hence the name "comfort air conditioning". Really, we should distinguish between "true", or "precision" air conditioning and "Comfort A/C". They are two different processes.

For "precision" air conditioning, as opposed to comfort A/C, the topics of interest include not only temperature but also those problems connected with humidity, and the quality of the air (dust, bacteria etc.)

As far as we are concerned, we will leave these considerations of "true" air conditioning to one side so that we can concentrate on comfort A/C and the traditional air conditioning system.

**Our aim is still to be able to understand how an air conditioning system works, so that we will know how to install it, commission it and ensure that it's maintained in the best possible condition.**

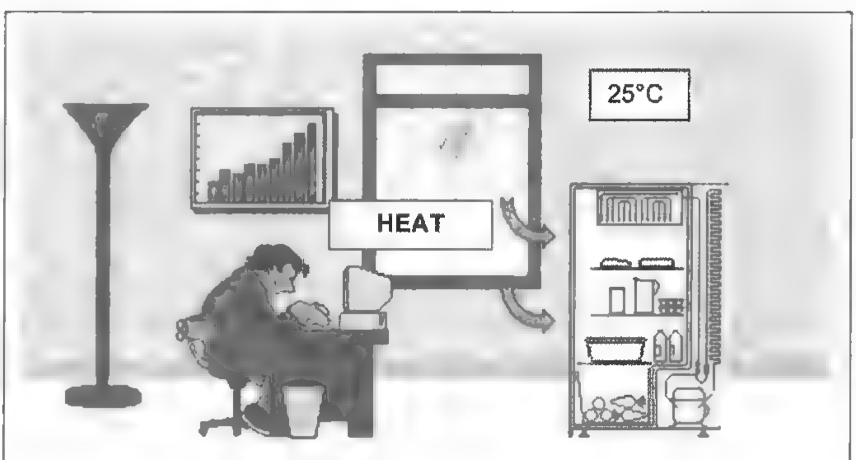
In the last chapter we studied the operation of a refrigerator. We saw that its role is to absorb heat at the evaporator...

So, for example, if we wish to air condition an office, couldn't we simply use a refrigerator, and leave its door open? In principle, if the fridge is capable of making ice cubes, why can't we use it to maintain twenty degrees Celsius in an office?

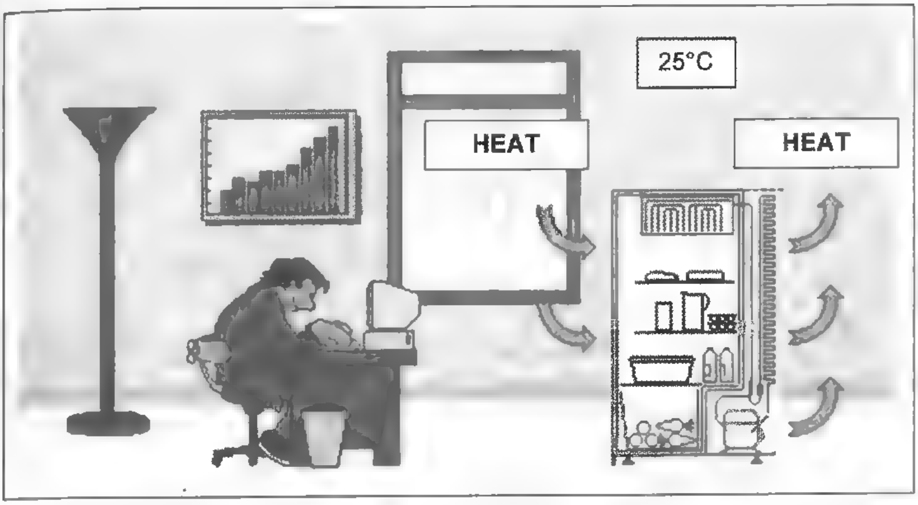
Let's think about this for a moment. If the temperature in the office is 25°C at the moment we open the fridge door, what would this temperature be in about an hour, say?


*Think about this for a while before continuing if you like...*

When we open the fridge door, some of the heat in the office will be absorbed by the evaporator: *the air in front of the fridge, therefore, will be cooled...*



Then, the heat absorbed by the evaporator will be transported via the compressor towards the condenser: as this device discharges heat, the *air behind the fridge will get warmer.*




Therefore, the air is cooled in front of the fridge, but heated behind the fridge: the heat absorbed by the evaporator is in fact entirely discharged by the condenser. As these two devices are situated in the same area, their effects will balance, and the temperature of the office will not decrease at all.

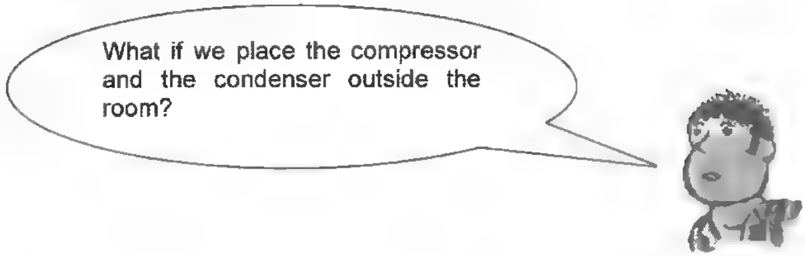
Furthermore, if you place your hand on the compressor, you'll observe that it's very hot (especially the lower part) because all motors heat up in use.

So, as the compressor motor heats up, and therefore emits heat, not only will the office not get any cooler, but on the contrary, *its temperature will actually rise!*

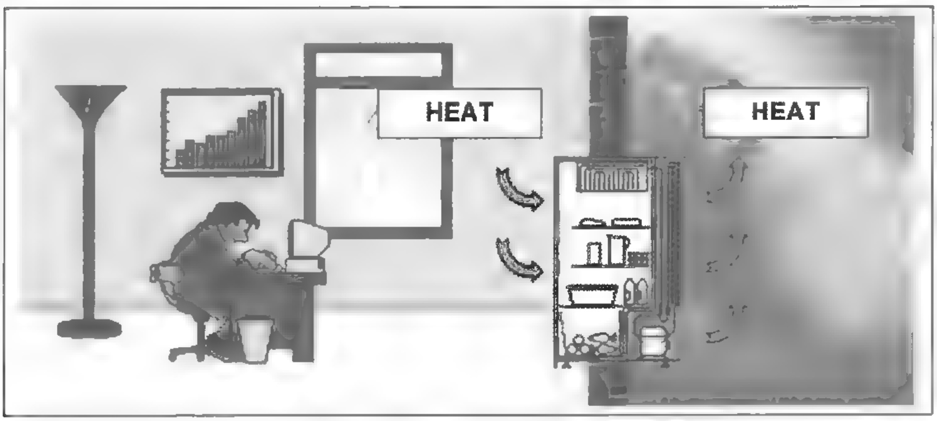
> ***The heat discharged into the office is equal to the sum of the heat absorbed at the evaporator and the heat produced by the compressor.***
> ***Therefore a refrigeration circuit discharges more heat at the condenser than it absorbs at the evaporator.***

So, If we open the door of a refrigerator to air condition an office, the temperature of the room will not decrease at all. On the contrary, the office temperature will increase.

*So, how do we proceed from here then?*




*Why not? What would happen?*




Now the heat absorbed by the evaporator will be discharged to the outside by the condenser: this would seem to work.

The office would be cooler, but unfortunately the temperature will only fall very slightly.

In actual fact, the refrigerating capacity of a refrigerator is very small, and would only air- condition a very small room indeed

Also, we'd need to make an enormous hole in the wall for the fridge to fit into. This would hardly be practical!

Finally, as the evaporator of a fridge is well below 0°C, the evaporator would permanently be iced up.

So we won't use a refrigerator to air- condition our office, but rather we'll look for a more powerful, less bulky device, with an evaporation temperature greater than 0°C to avoid frosting: *this is an exact description of an air conditioning unit.*

*Let's examine this a bit more closely…*

Let's replace our fridge with an air conditioning unit then:

The refrigeration cycle still works in exactly the same manner, but the refrigerator's technology has been improved and adapted. We'll study the details of this technology a bit more.

But just to put my mind at rest, then, is it only the refrigerator's technology that isn't applicable to comfort A/C? Is all the other stuff we've just learned about the refrigeration circuit still of use?


Of course it is. We only used the fridge to help us understand how a refrigeration system works. Now we can apply these principles to an air conditioning unit.

Great, that sounds cool!

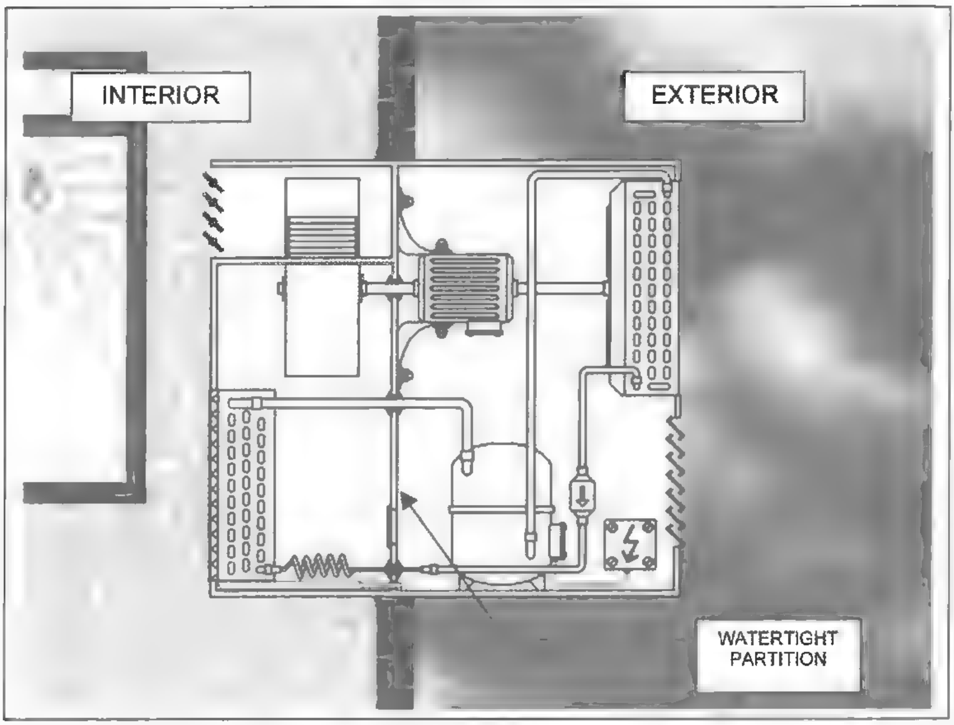
# THE WINDOW A/C UNIT

The unitary, or monobloc A/C unit, as its' name suggests, is made up of a single item of equipment.

Formerly this design was very common in use, but now it is considered to be slightly outmoded. It is often installed in a window space, from whence it gets its alternative name.

You have almost certainly seen this type of equipment, installed above the door of an hotel, over shop doorways, in offices etc.

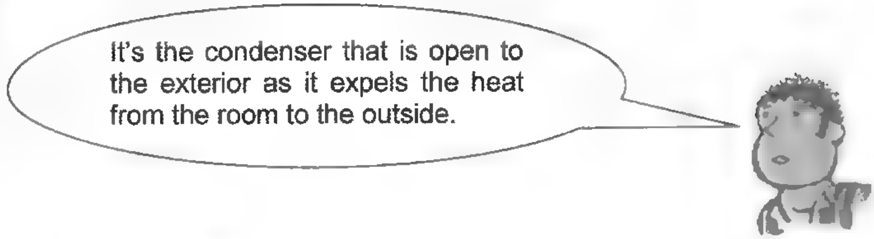
You'll notice from the diagram below that one part of the unit is on the interior of the room, whilst the other part is open to the exterior.




You'll also observe that the interior part of the unit is separated from the exterior part by a watertight (and air tight) partition or bulkhead.

*What do you think the purpose of this partition is?*

*Also, can you recall which part of the unit should be placed outside, and why?*

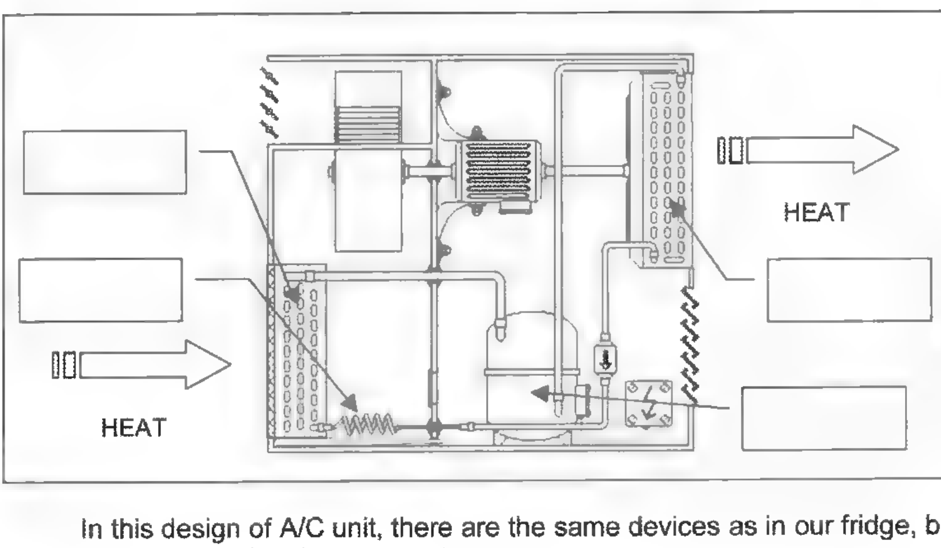




We've seen that a refrigeration circuit emits more heat from the condenser than it absorbs from the evaporator. So, if we want to cool a room, the condenser must necessarily be placed outside the room.

As for the compressor, not only does it discharge heat, but it is also the noisiest element in the refrigeration circuit. It would be better, therefore, to place it on the outside in order to reduce the noise level inside the air conditioned room as much as possible.

To help you identify each component of window air conditioning units, try and write the name of each element of the refrigeration circuit below:

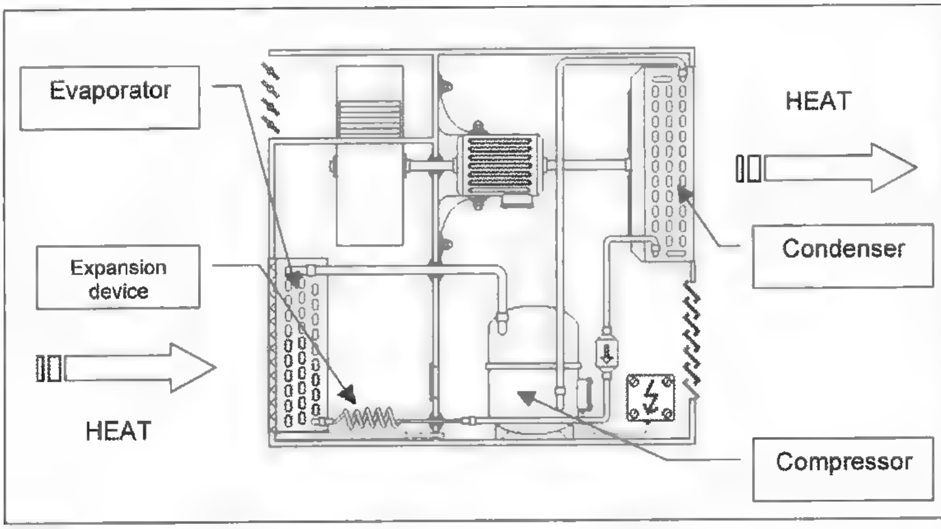



In this design of A/C unit, there are the same devices as in our fridge, but there are some additional components.

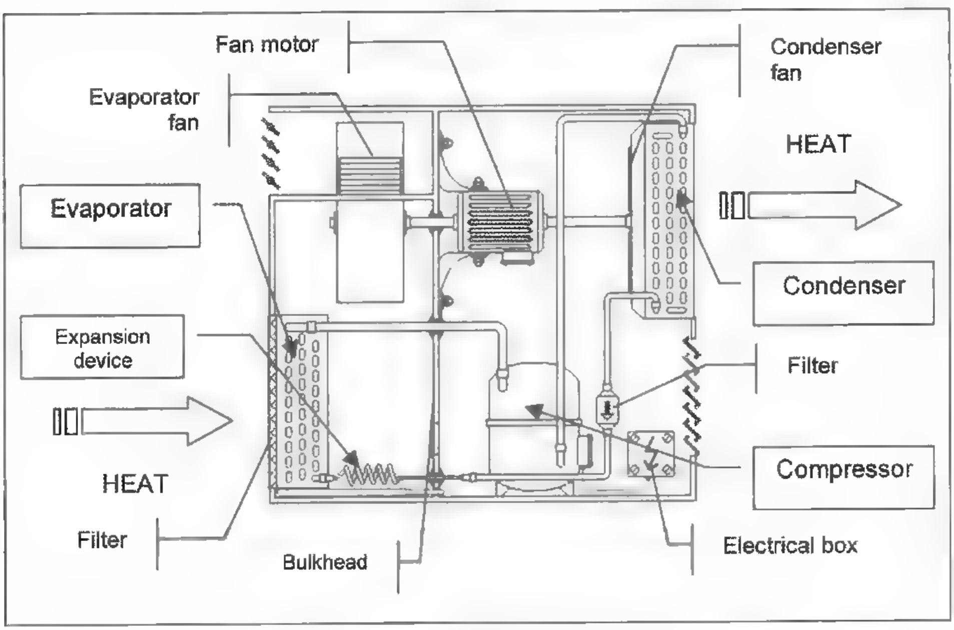
So, try and identify the filters (there is one in the refrigeration circuit, and one for the air), the fans, the motor that turns the fans, and the bulkhead which prevents any unwanted mixing of the air from the exterior with the air of the interior.

## Solution:

The names of the major components in an A/C unit:



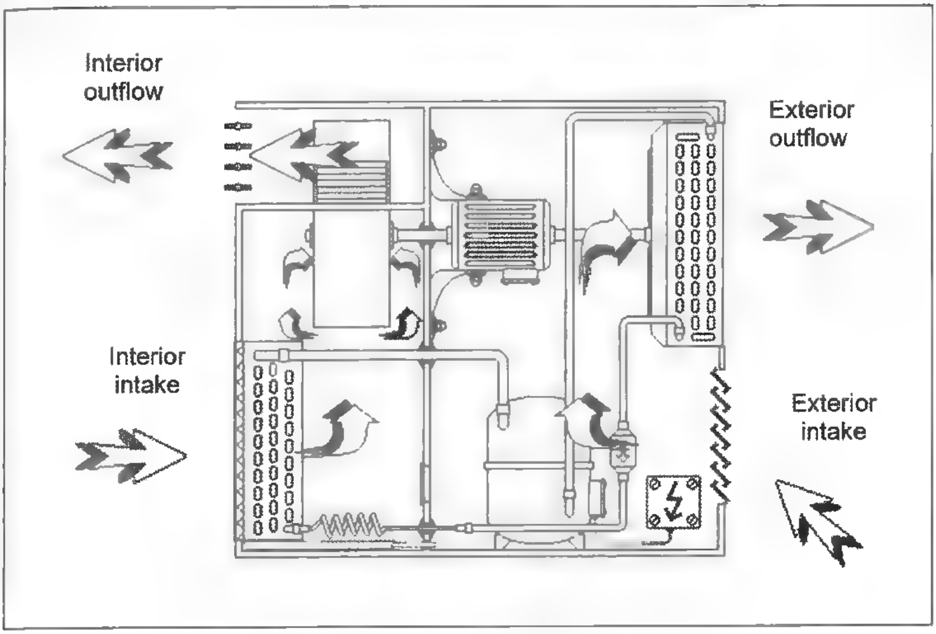

And now the names of some of the additional components:




It's important to understand that the bulkhead prevents any contact between the air on the interior, and the air at the exterior.

**A window A/C unit is not a machine that takes external air, cools it and then discharges it into the interior of the room!**

*If this is so, can you see how the air moves inside the unit?*



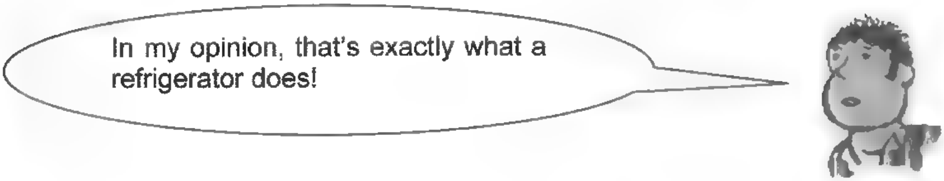

It is essential to understand that an A/C system is made up of three circuits: *one refrigeration circuit and two separate circuits for the air.* Let's look at them in more detail.

If we start with the air in the room, it is drawn in and passes through the filter, then over the evaporator. It leaves this heat exchanger having given up a part of its heat to the refrigerant. The fan draws in this cold air and emits it from the outflow grille. This first circuit causes the air in the room to cool by giving up its heat to the refrigerant, which then vaporises.

In the next stage, the vapour produced by the vaporisation of the refrigerant is drawn into the compressor. After being compressed here it is discharged in the form of hot HP vapour into the condenser.

Finally, the outside air is drawn in by the condenser fan and is blown across the condenser heat exchanger. Since the air is at a lower temperature than the refrigerant, it produces a thermal exchange, and the refrigerant gives up heat to the air. The air is therefore warmed up and the refrigerant condenses.

**Our A/C system doesn't manufacture "cold" then; it only pumps heat from the interior of the room in order to discharge it outside.**

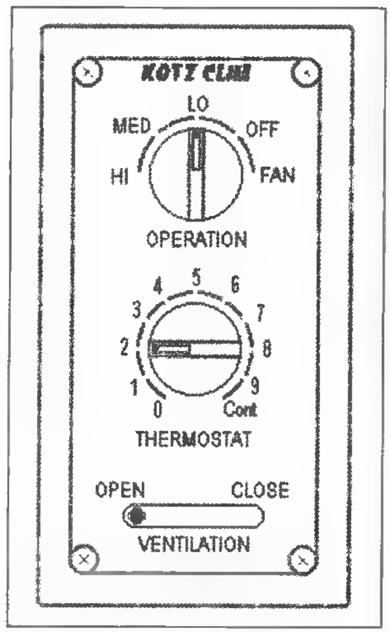


Indeed, the operation is identical to that of a refrigerator. Hot air arrives at the evaporator and gives up its heat to the refrigerant, which then vaporises. The air emerging from the evaporator is then blown into the air conditioned room at a temperature well below ambient.

Then the vaporised refrigerant is drawn in (via. the *suction line* of the compressor), compressed and discharged (via. the *discharge line*) to the condenser (the names of the pipework are shown on the diagram on page 105.)

Once at the condenser, the refrigerant is cooled by the outside air, which causes it to condense. The outside air, which passes over the condenser absorbs the heat of condensation, and is then discharged at a temperature greater than ambient.

After condensation, the liquid refrigerant (at HP) travels to the expansion device (through tubing known as the liquid line). It then expands and enters the evaporator (at LP) where it absorbs more heat. This cycle is continually repeated until the required ambient temperature is obtained.

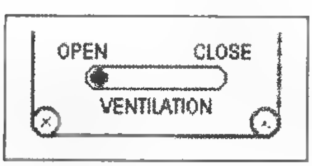



Once the desired temperature is reached, the A/C thermostat stops the compressor, and interrupts the refrigeration cycle.

The thermostat can be found either on the equipment itself (which is often the case for a window A/C system) or on a remote control unit.

On the control panel shown opposite, we can see at once that the thermostat control is set to position 2. Of course, a setting of '2' doesn't imply that the required temperature setting is 2°C, but is only there to give the user some sort of indication. The adjustment settings go from 0, the position where the compressor is never in operation, to "cont" (continuous) where the compressor is continually running.

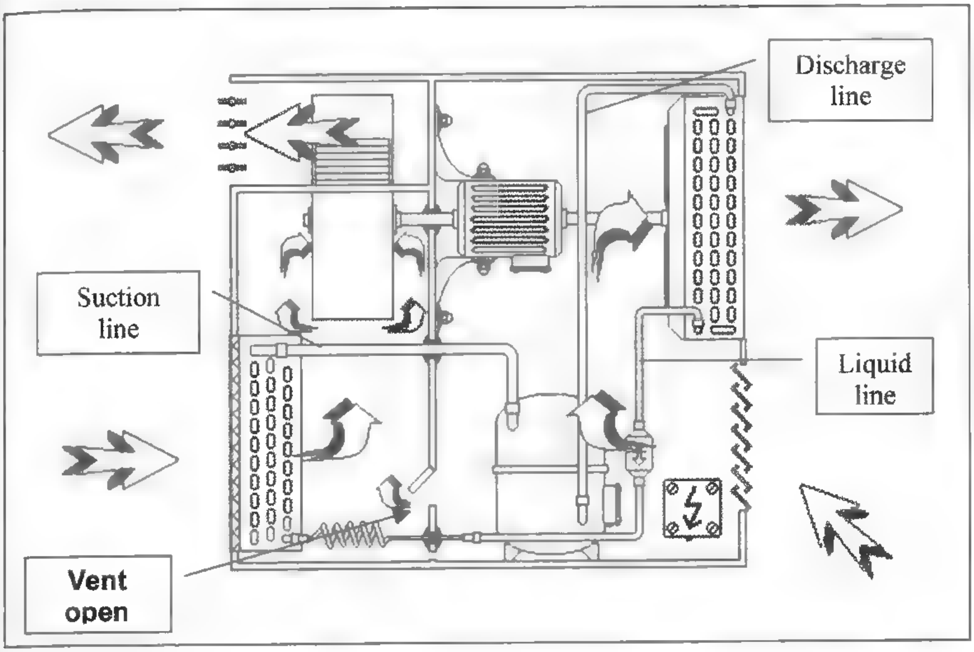
There are some thermostats available with temperature setting scales graduated in degrees. With window A/C units however, we frequently find thermostats that are very similar to the one shown in the above sketch.




We'll work on the installation of a control panel a little later on, but for now let's look at the ventilation function on the panel. The selector can be in the 'open' or 'closed' position. You should note now that the selector does not control the operation of the fan motor.

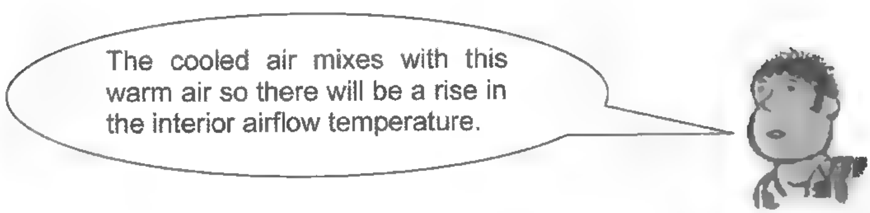
*So what is its real use?*

In a window A/C system, it is possible to allow a little 'fresh' air from outside into the room you are trying to cool. This is done using a small vent found on the separating bulkhead.




As you can see, when the vent is open a little way, air from outside can pass through the bulkhead. This air then mixes with the air coming from the evaporator, and is then drawn into the fan and blown out into the room. This supply of fresh air means that the air in the room is gradually replaced, a bit like when we leave a window half-open.

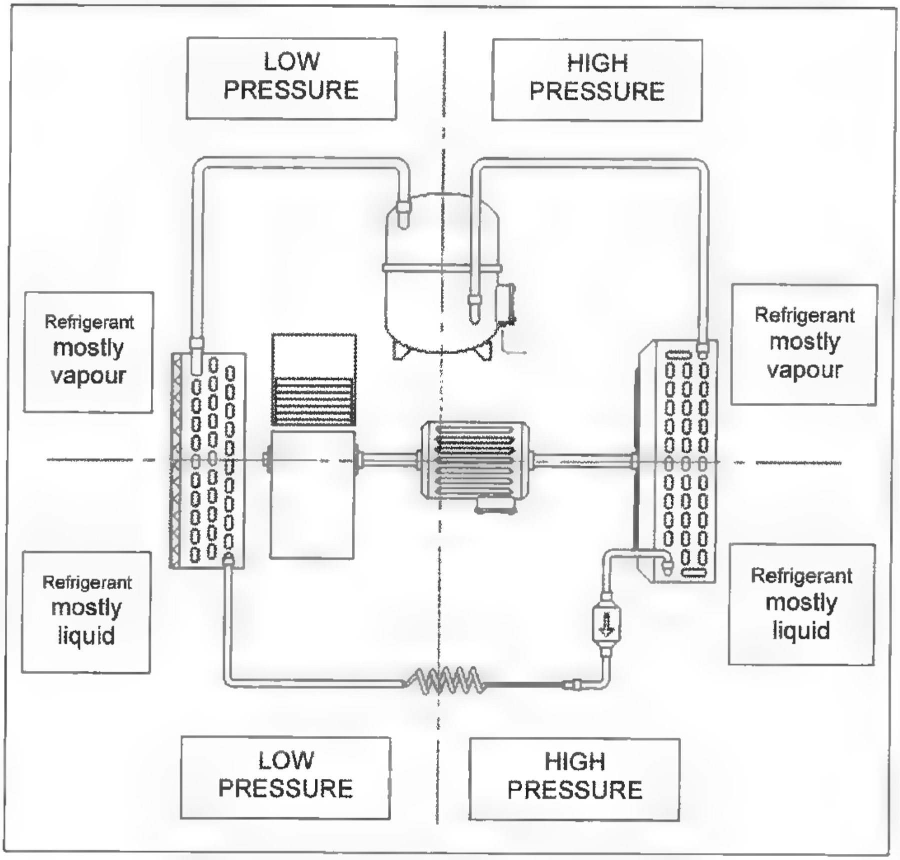
But what happens to the temperature of the air blowing into the room when this fresh air vent is opened?




Quite right. Since the outside air is much warmer than the air cooled by the evaporator, the temperature of the interior airflow will therefore rise. So, if the A/C unit is a bit short of capacity to cool a room, it's better not to leave the vent permanently open.

Now its time to remember what we've learned about the operation of a refrigerator so that we can apply it to the refrigeration circuit of an A/C system.

Although the technology of A/C equipment is somewhat different from that of a traditional refrigerator, the operation of its refrigeration circuit is exactly the same.




Just as with the refrigerator we saw earlier, the refrigeration circuit of an air conditioner can be broken down into four main sections; LP, HP, mostly liquid and mostly vapour.

We can see that the greatest differences lie in the heat exchangers. They are different shapes, and they are both equipped with a fan.

The cooling capacity of air conditioning systems is much larger than that of refrigerators. In addition, in order not to have very large equipment, thermal exchange is optimised by increasing the flow of air across the heat exchangers, and this is the reason for the fans.

We must always remember that 'comfort' implies that the appearance of our systems must be acceptable. It's essential that an A/C system is as compact and as discrete as possible.

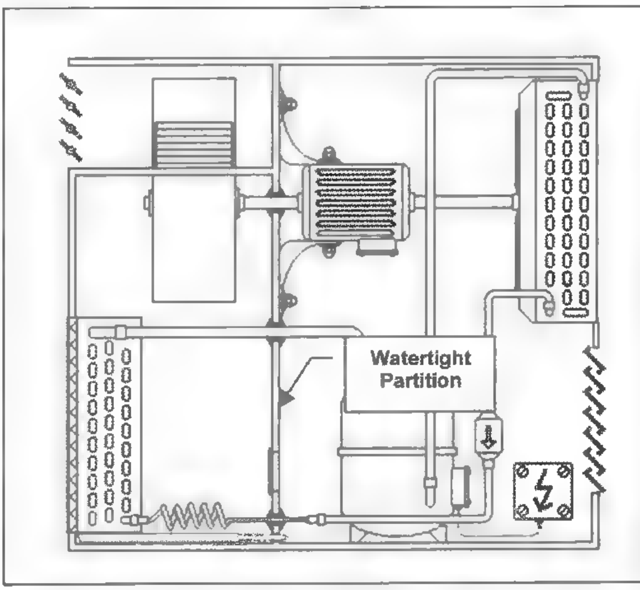
Our clients won't generally invest in conspicuous and ostentatious air conditioning to make their relatives jealous. They buy new cars to do that!

We've already seen that refrigerant is never consumed in any way. This is only strictly true if we obey certain rules. For example refrigerant cannot tolerate the presence of air, water or inappropriate oils. If we don't follow these rules, there is a risk of the refrigerant decomposing to form dangerous acids that can rapidly destroy compressor motors!

The major advantage of monobloc/window equipment lies in the ability of the equipment to be assembled, tested and charged in the factory, under near ideal conditions.

If the heat exchangers and the filters are regularly cleaned, the operating life of a window A/C unit can be as long as that of a refrigerator, without any servicing of the refrigeration circuit being required.

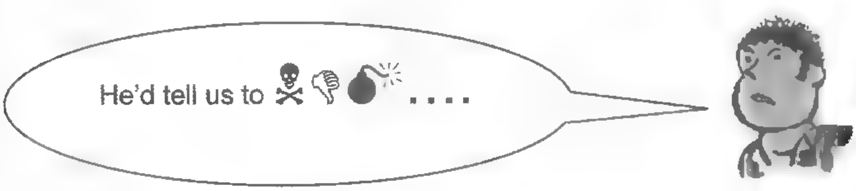
Unfortunately, the window A/C design possesses two serious drawbacks; It is not attractive in appearance, and above all it is rather noisy.




In use, besides the noise of the fans, the humming of the compressor is readily transmitted through the watertight bulkhead (this shuts out air effectively, but is noticeably less effective with noise!)

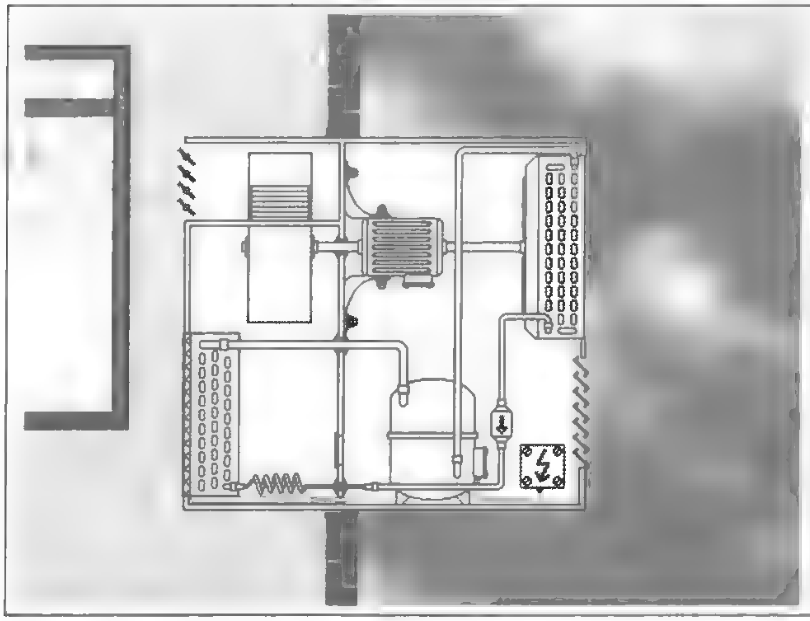
Nowadays, this sort of equipment is more often found in locations where appearance and noise levels are not a primary consideration. These include plant- rooms, motels, motorway tollbooths etc.

However, in the majority of cases, the noise produced by this sort of equipment is an important criterion. Imagine that a client has invested in air conditioning so that he is able to sleep when the nights are excessively hot. OK, he's no longer hot, but still can't sleep because the equipment makes too much noise. What do you think his reaction would be?




*So what could we do to avoid this problem?*

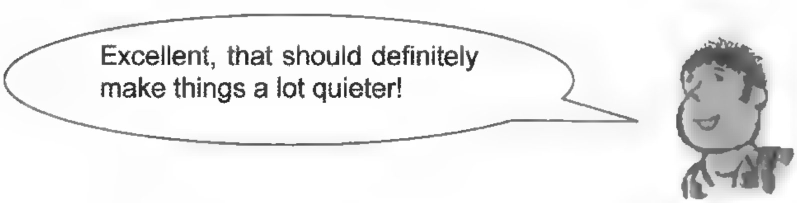
The noise is produced by the fans and by the compressor. To reduce the noise nuisance, we must place the noisy components and sources of vibration at a distance from the room we're in.



The partition in the middle of the equipment separates the interior and external air circulation. It is air tight, but allows noise to pass through. In addition, compressor vibration is transmitted via the equipment chassis and refrigeration pipework.

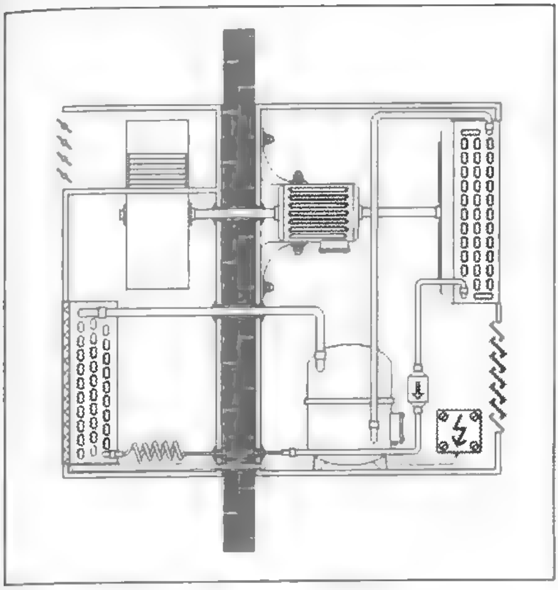
So, in order to improve our equipment, why not simply *cut it in two* where this partition is? In this way, we could install the compressor and condenser fan on the other side of a wall, which would allow us to eliminate the best part of this noise nuisance.

Of course, the evaporator fan must remain on the inside of the room, but this isn't too much of a nuisance, as it's the quietest element anyway.




*What do you think of this idea?*

To answer this question, what do you think of the set up that we've installed below?

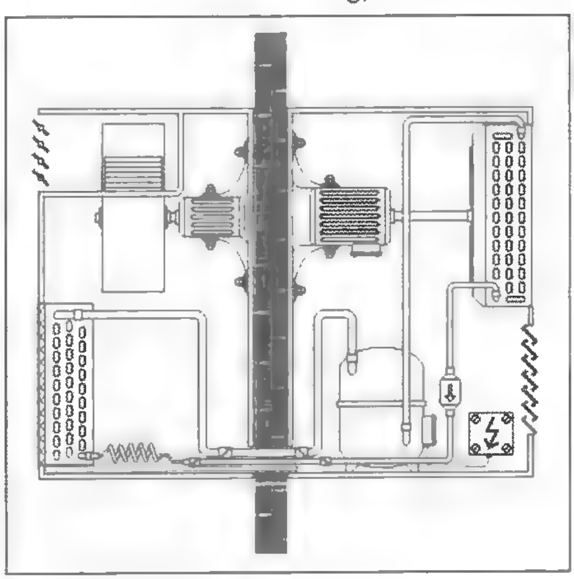


As Charlie said, if the compressor and the condenser fan were placed on the other side of a wall, the noise in the air- conditioned room would certainly be at a much-reduced level.

Does this system look OK to you? The refrigeration circuit shown would appear to be perfectly viable, and there is no reason why this set up shouldn't operate with a minimum of noise!

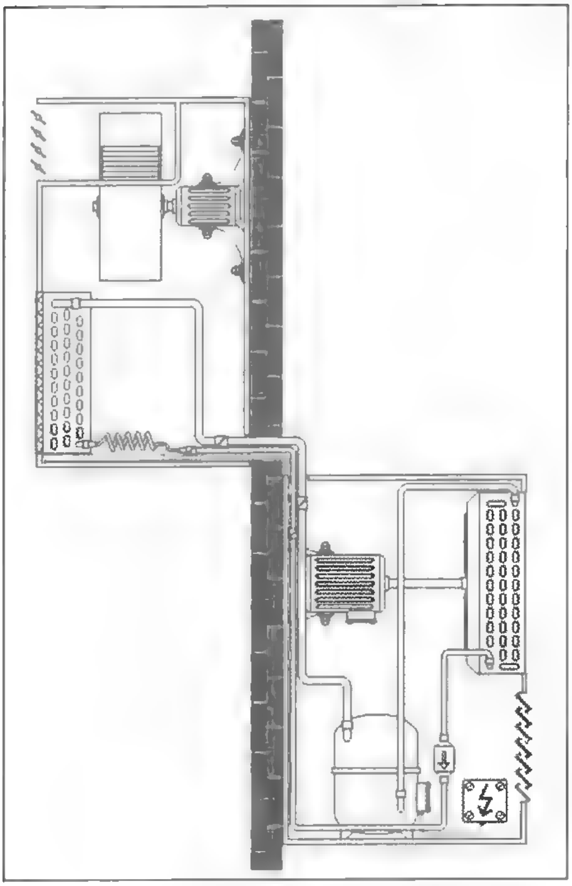
*You think its OK?? Are you kidding?* Have you thought about me? *How am I going to install this equipment?*

There is a danger of this design being rather fragile. The evaporator fan is, admittedly, situated in the room that we're air conditioning, but the motor is on the exterior, and its shaft passes through the wall! At the time of construction, if we want the fans to actually rotate, we must ensure that the interior and external parts of the air conditioner are perfectly aligned. This design will not really be very practical!



In actual fact all we need to do is add a second motor to turn the evaporator fan if we want to eliminate this problem. We can then choose a low noise fan motor assembly.

With this modification we have just changed our original monobloc A/C into a sort of " twin-bloc "...



One part will be located inside the air– conditioned room, and this part will hold the evaporator and its fan and motor. **This part is known as the internal unit.**

The second part will be located on the outside of the air- conditioned room, and this part will hold the condenser, its fan and motor and also the compressor. **This part is known as the external unit**, but is often also called the condensation assembly, or condensing set (as its function is to condense the refrigerant)

You'll observe in the sketch opposite, that by splitting the air conditioning unit in two, the external unit doesn't necessarily have to be installed exactly opposite the internal unit. As the two parts are connected by pipework, they can actually be located at different levels.

The capillary expansion device is located within the interior unit in this instance, but in some cases, it is installed as part of the external unit.

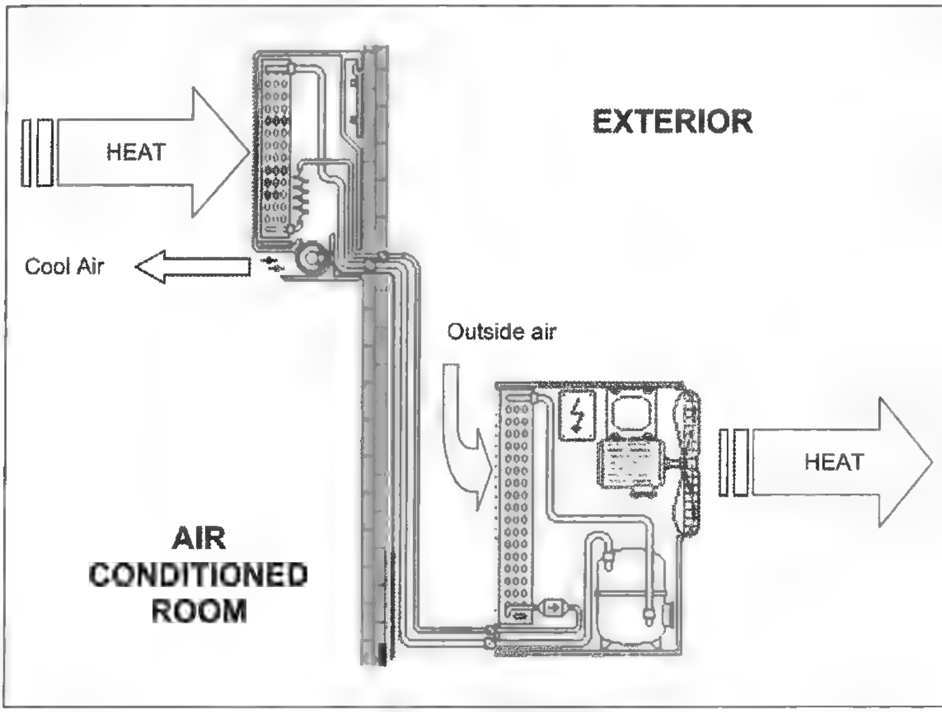
For those A/C systems that are of modest refrigerating capacity, (for example, those designed to air- condition bedrooms) manufacturers often prefer to place the capillary in the external unit. In this way, the occupants don't hear the whistling made by the capillary when the compressor starts and stops.

A/C equipment of this type, made up of two distinct units, is called ***split system air- conditioning***.

# SPLIT SYSTEM A/C UNITS

As we've just seen, this type of A/C system is made up of two parts; the internal unit and the external unit. These two units are connected to each other by two lines of refrigeration pipework and by an electrical connection.

Here is an example of a split system configuration:



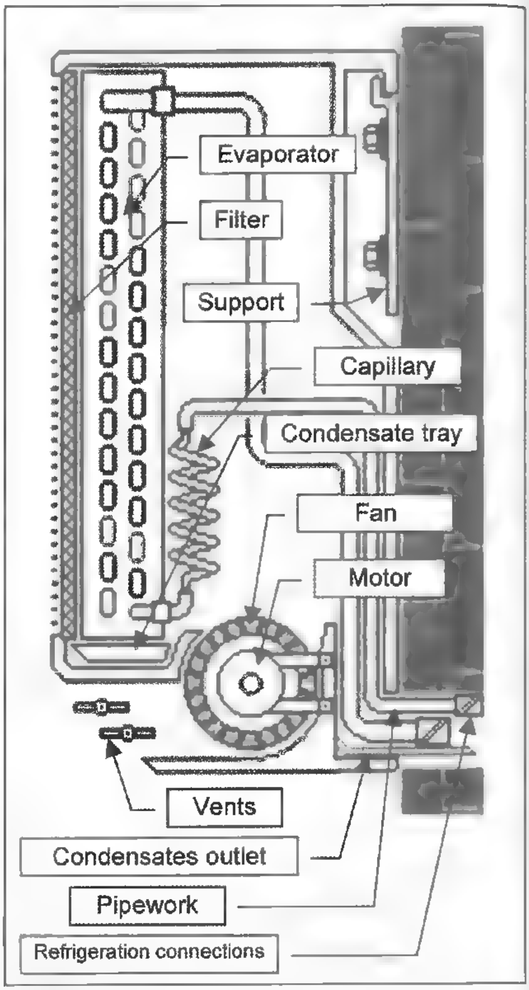

As with the window A/C unit, the split system removes heat from the air-conditioned room by means of three circuits: *one refrigeration circuit and two air circuits.*

The split system is the commonest type of air conditioning in use today. We will use it for the major part of our studies from now on. We will learn about its operation, the technology it uses, its installation, commissioning, maintenance and simple repairs.

Before looking in detail at its operation, we'll try and become better acquainted with its various constituent parts.

*Although the diagram above is a bit small, why don't you try and identify the different components before turning the page?*

## Let's start by examining the Internal Unit:




**The support:**
This fixes the internal unit to the wall. People refer to these as wall mounted A/C units.

**The filter:**
This filters the air before it passes over the evaporator.

**The evaporator:**
This is the thermal exchanger where ambient air is cooled.

**The fan:**
The evaporator fan (which is often of a tangential design) draws air from the room across the evaporator and then blows it out through diffusion vents.

**The vents:**
These may or may not be motorised, but they are always adjustable to allow a choice of direction of the flow of cold air.

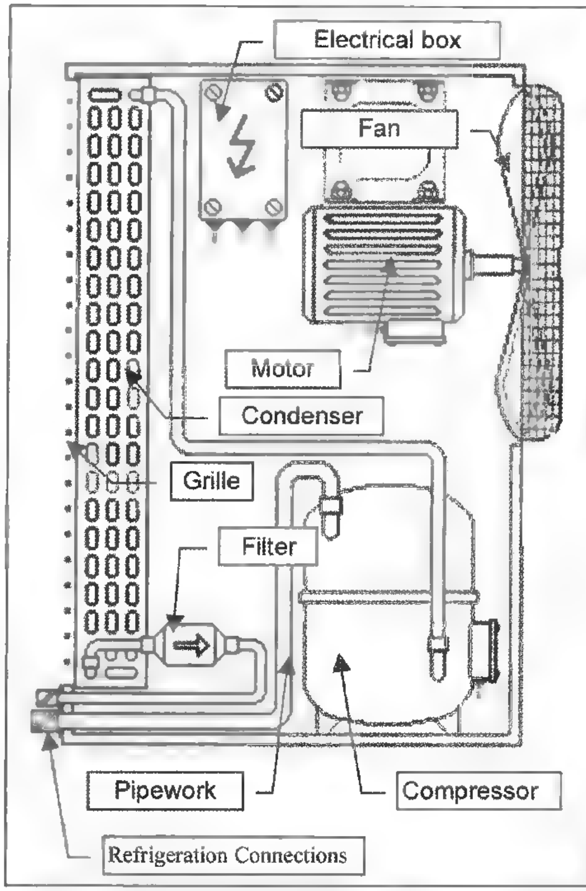
**Refrigeration connections:**
These special connections allow the connection of the internal and external units. There are basically two types of connection - 'quick' connections or 'flare' connections', and we'll study these a little later.

**Pipework:**
This allows the flow of refrigerant between the two units. It is fabricated from refrigeration grade copper pipe. *Warning: sanitary grade copper piping is not suitable for use in refrigeration applications!*

**The expansion device (capillary):**
In comfort A/C, expansion devices are essentially made up of a very fine tube called a capillary. On certain equipment, the capillary is found in the external unit.

**Condensates:**
As it passes over the evaporator, ambient air is cooled, and a part of the water vapour contained in this air condenses. This condensate is collected in a tray situated beneath the evaporator to be led away to the exterior of the room by an outlet pipe.

## Now let's examine the External Unit:




**Grille:**
Its function is to protect the fins of the condenser from damage.

**The condenser:**
This is the thermal exchanger where condensation of refrigerant takes place.

**The Fan:**
This 'axial' fan draws external air across the condenser and discharges it to the exterior through the protective grille.

**Refrigeration connections:**
These special connections are designed to allow connection with the internal unit.

**Pipework:**
These copper pipes allow the flow of refrigerant; it is essential that they are fabricated from refrigerant grade copper pipe.

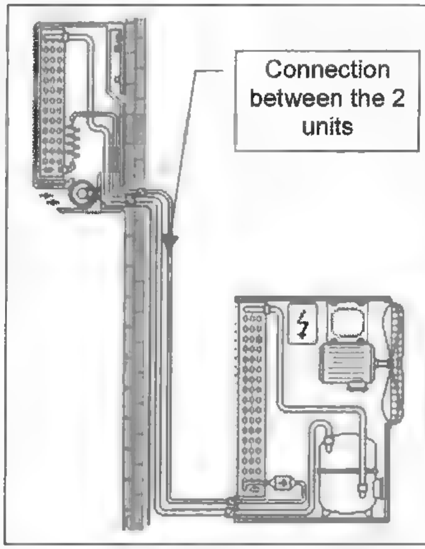
**The Compressor:**
The compressor shown here is of the hermetic type; that is, it cannot be opened for repair. Up until this point we've only discussed the operation of a piston compressor in detail, as the operation of this type of compressor is the easiest to understand. However, there are also hermetic rotary and screw type compressors in use, and we'll discuss the operation of these types of compressors later.

**The Filter-Drier:**
Its role is to filter the refrigerant in order to prevent possible impurities from blocking the very narrow orifice of the capillary. It is also designed to remove water from the refrigerant, as water is mortal enemy of the refrigeration engineer: refrigerant + water = strong acids = death of the compressor.

**Electrical box:**
This box is included for the connection of a power supply to the unit, and to allow electrical connections between the internal and external units.

*Now all that we need to do is join the two units together!*

In order to connect the units to each other we will use:




- *Refrigeration grade copper tubing* connected between the refrigeration connections of the internal and external units.
- *A control cable* enabling electrical signals to be passed from one unit to the other.
- *A condensate outlet pipe* if there is no feasible method of removing condensates on the interior.

**Warning:** We can never ignore the phenomenon of condensates at the evaporator. Since the quantities of water that condense can reach several dozen litres, it is always essential to make arrangements for its removal. If you don't, then you can be sure that condensates will cause you trouble!

**Remarks:**

- Depending on the design and capacity of the equipment, the electrical supply may be made to the internal unit, or the external unit, as single phase 220/240V, or as three phase 380V.

- It will be necessary to thermally insulate at least one of the two connecting refrigerant lines, and sometimes both, according to the type of system.

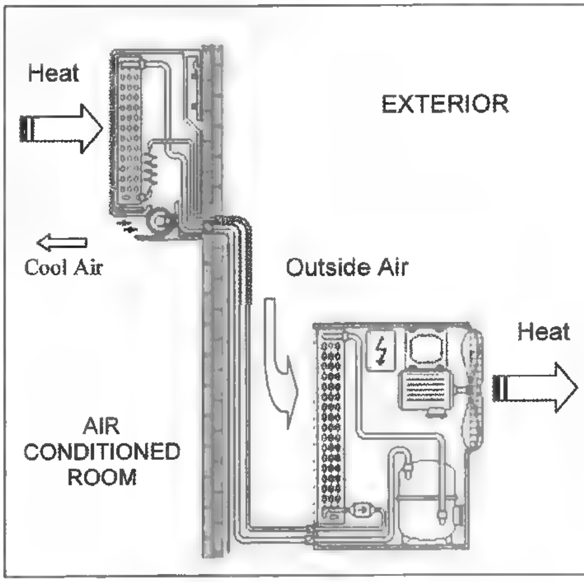
- Whatever type of A/C unit is installed, the two units must always be suitably mounted to minimise any vibration. The 'Comfort' that is provided by A/C in the form of pleasant ambient temperatures should never be compromised by annoying acoustic effects.

- 'Comfort' also has an aesthetic aspect. The choice of an internal unit's location should never disfigure a room. It should also allow good circulation of the treated air, easy removal of condensate, and the shortest possible refrigerant pipe runs. All these must be accomplished within the manufacturer's recommended limits. To do all this isn't always that easy!

- The choice of an external unit's location should similarly never disfigure a building, whilst it should meet all building regulations. Take care, because some buildings may be listed, and it may be forbidden to install anything at all on their exterior.

*Now, let's examine the refrigeration circuit a bit more closely…*

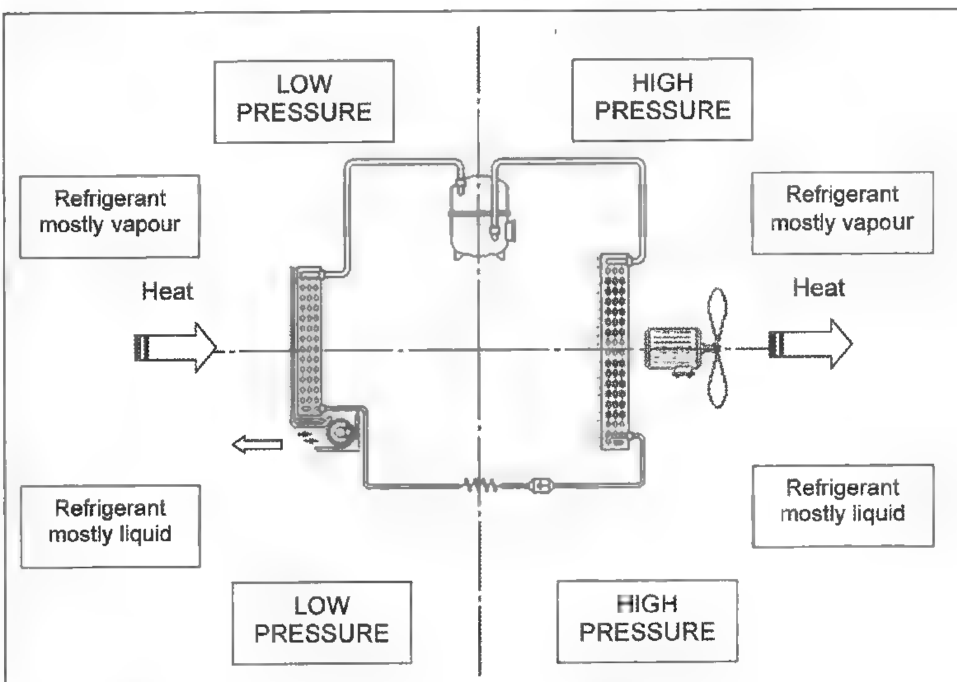
The operation of the refrigeration circuit in a split system air conditioning system is in all ways identical to that of a window A/C unit. The most significant difference is associated with the evaporator fan, which is equipped with an independent motor.




You've already seen the diagram opposite where the ambient air in a room passes over the evaporator and emerges cooler whilst the outside air passes over the condenser to emerge warmer.

As with all refrigeration circuits, heat is pumped out of an air-conditioned room by the system, and then discharged to the exterior.

As a reminder, you'll see below a split system circuit with its various pressures and various physical states of its refrigerant.




It is important to understand that all compression refrigeration systems use exactly the same operating principles...

We should remind ourselves that on each circuit, the refrigerant passes through the same components, in the same physical state, and with the same properties. It is never consumed.

For these reasons it is essential that we protect the system from anything that could cause it to deteriorate, e.g. air, water, inappropriate oils etc.

In contrast to monobloc (window) A/C systems (which consist of a single unit), split system units cannot be completed or tested in the factory. The installation engineer himself must complete the connection of the refrigerant pipework connecting the 2 units.

The installation of a split system unit demands a modicum of care if we wish to avoid premature deterioration of the refrigeration circuit. That is why you will find in this manual all those elements that will allow you to accomplish installation of systems in accordance with best practice.

Before we look in further detail at the actual installation of a split system A/C unit, we'll first of all complete our study of its operation. This will give us a better understand of its operational limits, the difficulties involved in installing a system and any faults that may occur.

***Now that you properly understand the operating principles of an air conditioning system, we'll move onto more serious issues, and discuss operating pressures and temperatures.***

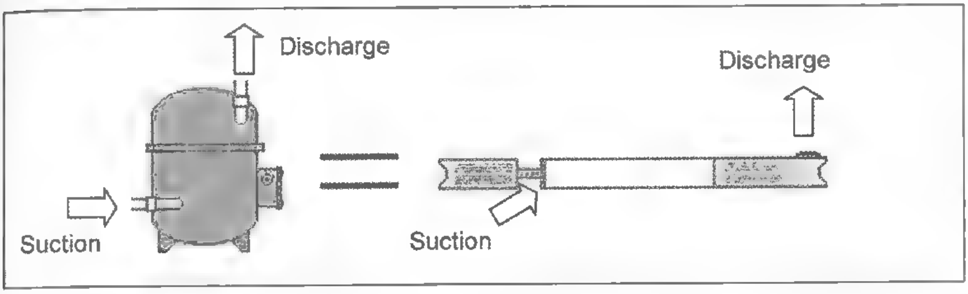
We should remind ourselves here that the aim of the ***REFRIBASE*** training program is to allow you to understand the operation of 'comfort' Air conditioning.

But all the principles learned here can be applied to a multitude of other equipment. In real terms, for a refrigerator, air conditioning, cold chambers, blast freezers, ice-cube machines, water- cooled nuclear reactors etc. the differences are only those of operating temperatures, and the technological peculiarities of the equipment involved.

*But in each of these there is as a minimum a compressor, a condenser, an expansion device and an evaporator!*

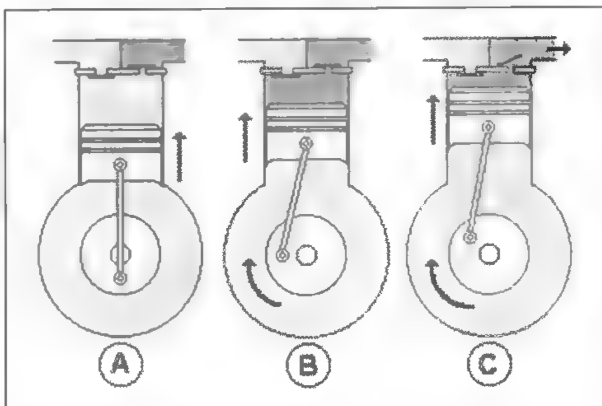
# THE PISTON COMPRESSOR: NORMAL FUNCTION

As we saw earlier, the piston compressor works exactly like a bicycle pump. The principle difference arises from the fact the compressor is driven by an electric motor.

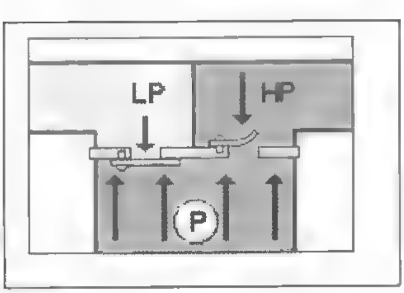



Their function is absolutely identical: *to draw in gas and then discharge it.*

Let's remind ourselves how this compressor operates:

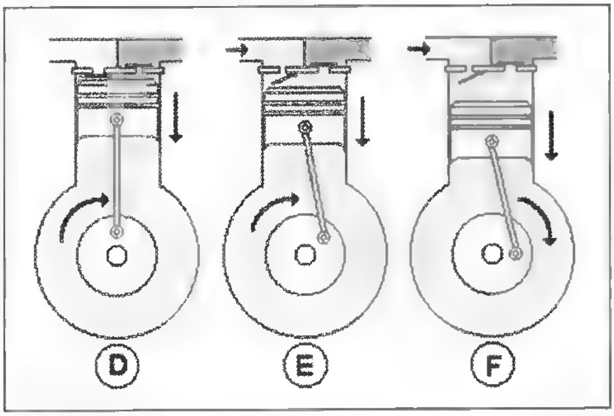



- At **A**, the piston is at bottom dead centre *(BDC)*. The cylinder is completely full of refrigerant vapour at low pressure.
- At **B**, the piston rises in the cylinder and compresses the vapour. The pressure and temperature in the cylinder are continually increasing and the valve reeds remain closed and gas- tight.

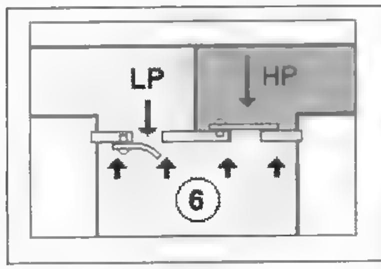



- At **C**, the pressure of the vapour in the cylinder becomes *just greater* then the HP that exists above the discharge valve and *the valve opens*. Because of the difference in pressure between one side of the LP valve and the other either, this remains closed and gas- tight. As the piston continues to rise, the HP vapour is expelled into the discharge pipework.

**This pressure difference alone causes the opening (or closure) of the HP valve.**




- At **D**, the piston has reached piston Top Dead Centre (*TDC*) and it starts its descent.
- At **E**, the piston continues its descent. At the moment when the pressure in the cylinder becomes *just less* than the **LP** pressure, the suction valve opens. At this point LP vapour is swept into the cylinder as the piston continues to descend.

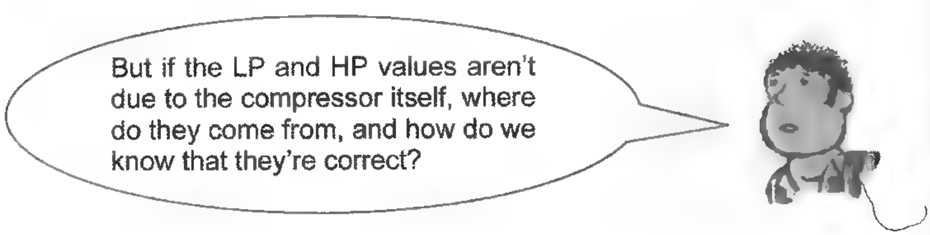



- At **F**, the piston continues to move downwards in the cylinder until it reaches bottom dead centre (BDC). At this point, the cylinder is completely full of LP vapour and the suction valve shuts.

The compressor shaft has now made one complete revolution and the piston has made one complete rise and fall in the cylinder: we have therefore returned to our starting point. The cylinder is completely full of refrigerant vapour at low pressure, and the piston is about to start rising in the cylinder once again…etc.

**The pressure difference alone causes the opening (and closure) of the LP valve.**

The opening of the LP and HP valves is entirely due to the pressure difference between the gas trapped in the cylinder, and the **LP** and **HP** pressures. It is essential that you clearly understand that **the compressor does not control the value of the LP and HP pressures**. It simply functions as a sort of *lift* that allows **the vapour to rise from the LP pressure level to the HP pressure level**.

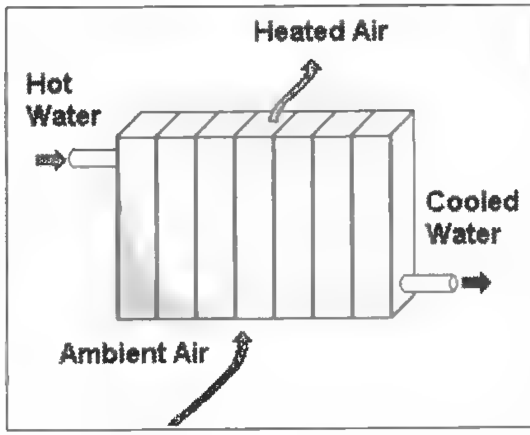



*We'll start to answer this very important question in the next chapter…*

# THE AIR-COOLED CONDENSER: NORMAL OPERATION

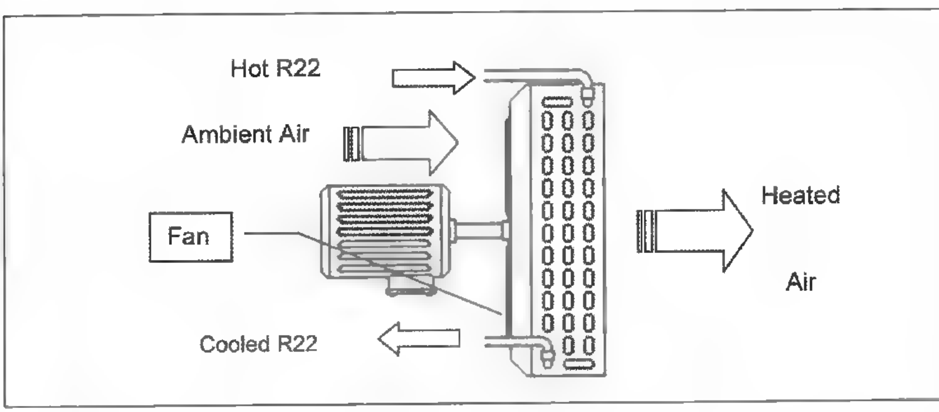
The air-cooled condenser is a heat exchanger. Can you remember the significance of this?

Do you remember the principle of operation of the central heating radiator? This particular type of heat exchanger allows us to warm the air in a room by exchanging heat between the hot water flowing inside it and the colder air on its exterior.

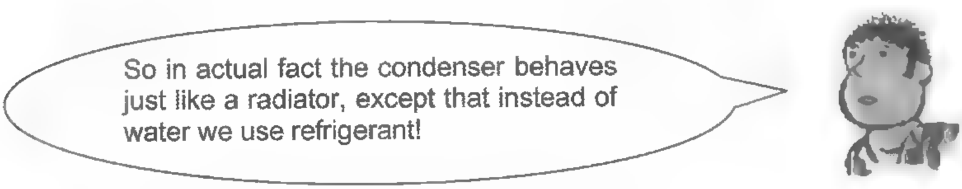



This thermal exchange is only possible if the water and the air are at different temperatures.

The operation of the condenser is exactly the same. Heat exchange occurs because the refrigerant (R22) and the air are at different temperatures.



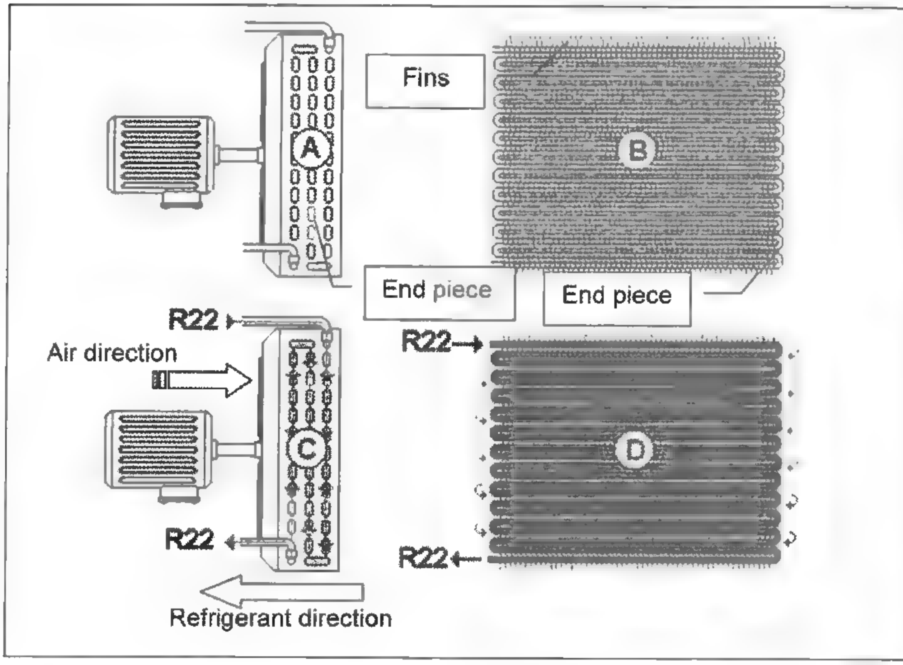

Just as with the air and water in the radiator, the refrigerant and air exchange heat. The major difference is that the condenser in an air-conditioning system is equipped with a fan to encourage the heat exchange.



Now let's look a bit more closely at the condenser below, concentrating on the direction of the flow of the refrigerant and of the air.

- At **A**, you'll see the condenser and its fan viewed from the side. You see two pipes, one connected at the top of the condenser, and one at the bottom.

- At **B**, the condenser can be seen face on. You can distinguish the fins (which increase the exchange surface) and the end pieces, which serve to connect the horizontal tubes together at either end of the heat exchanger.



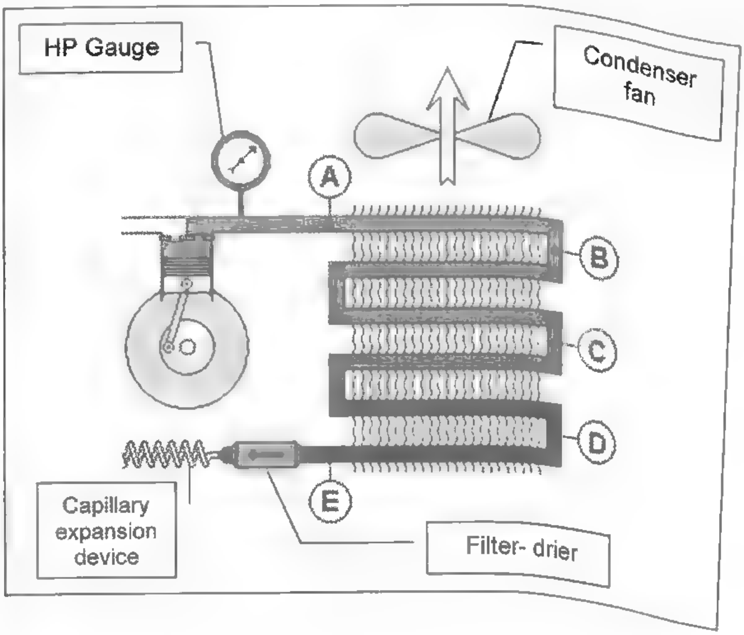

- At **C**, the R22 enters the condenser via. the top right hand pipe, and it emerges from the bottom left hand pipe, whilst the air flows from the left towards the right. *The refrigerant and air therefore flow in opposite directions.*

  We say that the refrigerant and the air are in **counter current** flow. This type of flow improves the effectiveness of the heat exchange between the two fluids. You should note that if the air and the R22 flow in the same direction, the flow is said to be concurrent.

  A counter current heat exchange is preferable as it allows us to obtain the same cooling capacity with a smaller heat exchanger. In this way we can reduce the bulk and cost of the equipment.

- In **D**, you can see the flow of refrigerant in the heat exchanger viewed face on. The hot vapour that arrives at the condenser from the compressor outlet enters at the top and then condenses. Since the liquid refrigerant is heavier than the vapour, *the liquid refrigerant collects of its own accord at the bottom of the condenser.*

***At this point, with the help of the diagram below, we'll examine more closely the changes in the refrigerant as it passes through the condenser from points A to E.***




<u>**Point A:**</u>

R22 vapour arrives from the compressor at a high temperature and at high pressure (HP).

For example, let's imagine that a high pressure reading of 16.3 bar is indicated on the HP gauge.

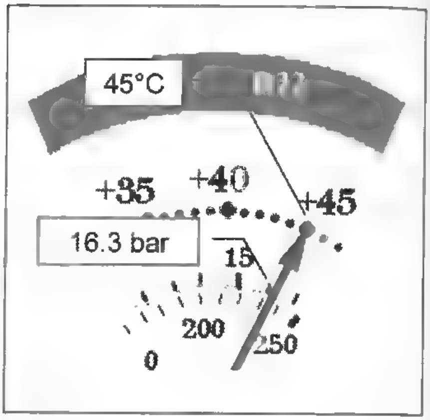
This indicates that the pressure on the HP side is 16.3 bar. But what does the **temperature** indicated on the gauge actually mean?

*Note that we refer to this as an "indicated" temperature and not as a temperature that is "measured" by the gauge.*


In actual fact, **a gauge is a device that measures pressure**, and pressure only. It is not capable of *measuring* temperatures. We can only say that the refrigeration gauge can *indicate* a temperature. We need to understand just what this *indicated* temperature means.

*What do you think that the indicated temperature on the gauge refers to?*

The temperature indicated on the gauge is 45°C.

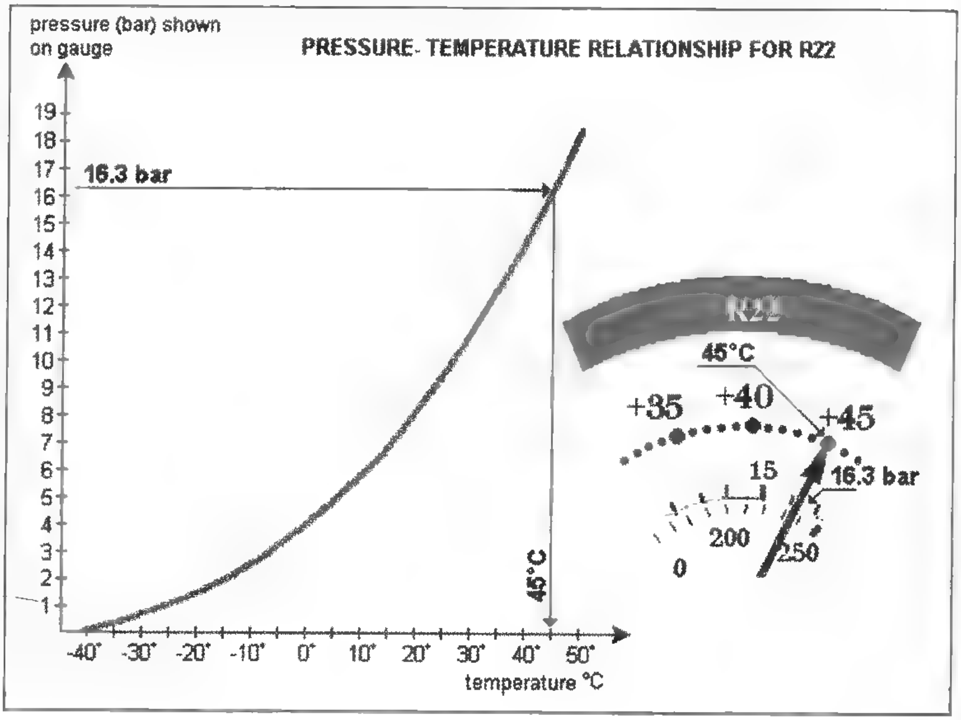



**Yet if we measure the refrigerant temperature at the compressor outlet, a thermometer reading would give a much higher temperature, let's say 75°C!**

So, a gauge connected to the compressor discharge pipework adequately measures the discharge pressure, but all the evidence suggests that it cannot measure the temperature of the refrigerant in the pipe; if it could it would read 75°C and not 45°C!

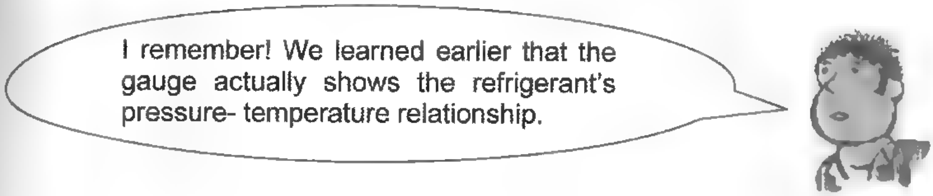
*But what does the 45°C reading correspond to?*

Try and recall our study of the pressure temperature relationship for R22 (studied on p48), and look at the diagram below:




On this graph we can see that at 16.3 bar, the condensation of R22 occurs at 45°C. On the gauge we see that the needle shows exactly 16.3 bar at 45°C, exactly as it should from the graph.

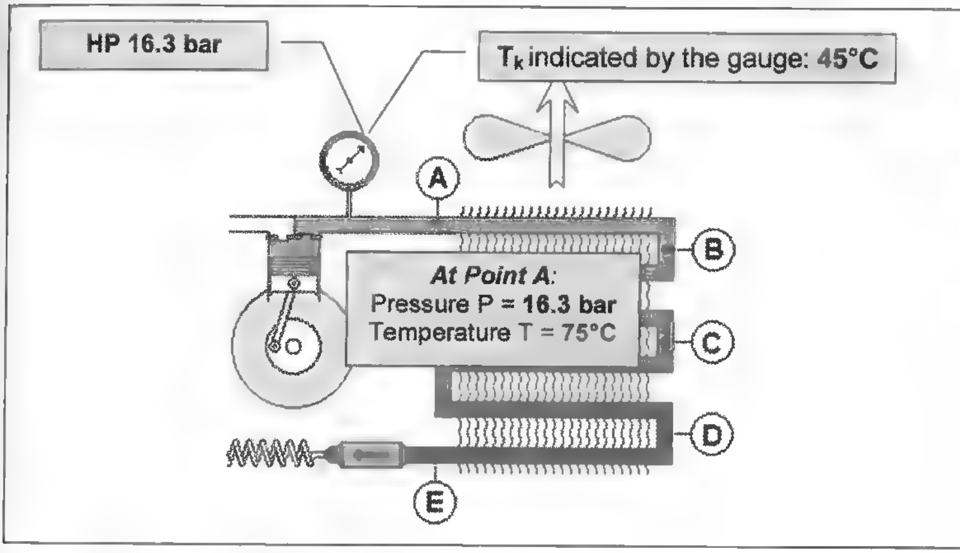
*What conclusion can you draw from this?*




Charlie is right. The temperature shown on the gauge is that given by the pressure-temperature relationship of R22. It simply shows that at 16.3 bar, the change of state for R22 occurs at 45°C.

The pressure of the refrigerant at point A is therefore 16.3 bar (the pressure measured by the HP gauge). On the other hand, the temperature is actually 75°C (measured with a thermometer).

Note that many refrigeration engineers use the symbol $\mathbf{T_k}$ when they are referring to the temperature at which condensation occurs. It means exactly the same thing and is much shorter, so it's a useful abbreviation to remember.




So, on the high pressure side, the gauge indicates that the temperature at which the condensation takes place ($\mathbf{T_k}$) is 45°C.

On the other hand, at point A, the temperature of the vapour is 75°C, that is, it's greater than $\mathbf{T_k}$ by: 75 – 45 = 30°C.

In the language used by refrigeration engineers, we say that the vapour at A is a **superheated vapour**, that is, its temperature is greater than $\mathbf{T_k}$.

More precisely, we could say that since the temperature of vapour at A is greater than $\mathbf{T_k}$ by 30°C, *it is superheated by, or has a superheat of, 30°C.*

**From point A to point B:**

***Before we continue,*** we must understand that in small refrigeration systems, like those installed in 'comfort' window or split- system air conditioning units, there are only two pressures present in the systems when they are in operation:

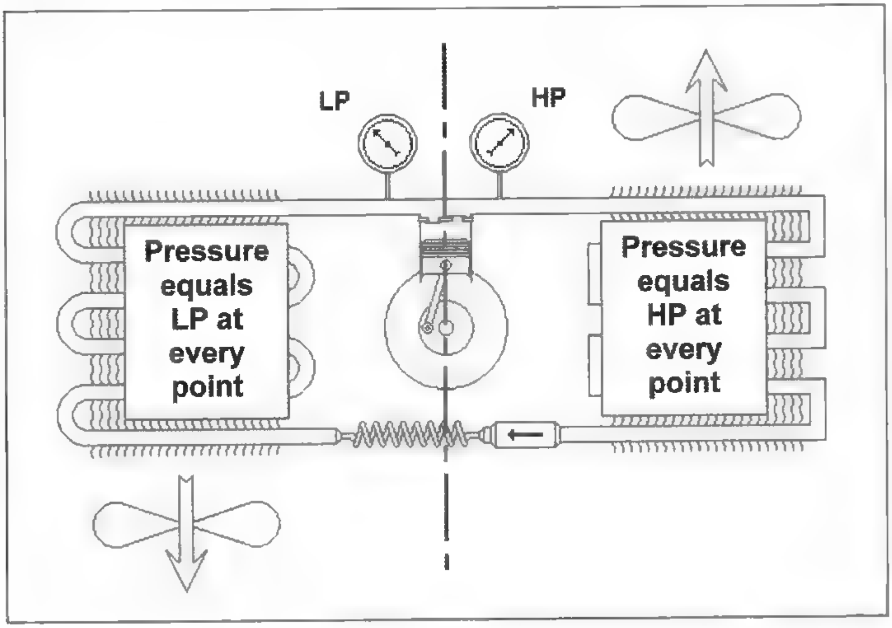
- *High Pressure HP*, which is to be found from the outlet of the compressor to the inlet of the expansion device (by way of the condenser).

- *Low Pressure LP,* which exists from the outlet of the expansion device up to the inlet to the compressor (by way of the evaporator)

As the lengths of pipework are generally fairly short in 'comfort' Air Conditioning, any pressure drops that this causes are negligible. That is to say, the pressure of refrigerant only falls by a very small amount as it overcomes the resistance due to pipework.

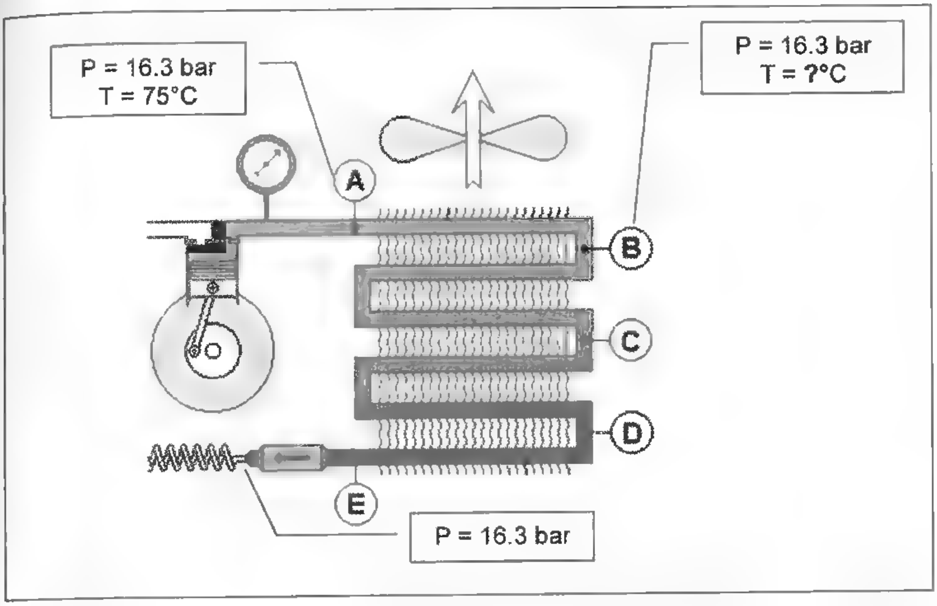
We can assume then that the pressure that is found at the inlet of the condenser is the same at that at the outlet.

**We can therefore say that, at every point in the circuit between the compressor outlet and the entry to the expansion device, the pressure will be the same as the reading on the HP gauge.**




For the same reasons, you should note *the pressure at every point in the low-pressure circuit between the outlet from the expansion device, to the inlet of the compressor, will be the same as that read on the LP gauge.*

But what happens between A and B?




Since the temperature of the air that passes over the condenser is less than that of the R22, the refrigerant will continue to cool.

The superheated R22 vapour will therefore cool until it reaches the change of state temperature, that is, the condensation temperature $T_k$. The vapour will pass from 75°C to 45°C, that is, from the superheated vapour temperature to the condensation temperature $T_k$.

This area of the condenser between A and B, is known as the de-superheating zone. In this zone the temperature of superheated vapour falls until it reaches the condensation temperature.

As it passes through the de-superheating zone, the refrigerant releases its heat to the air. Do you think that this heat is sensible heat, or is it latent heat?

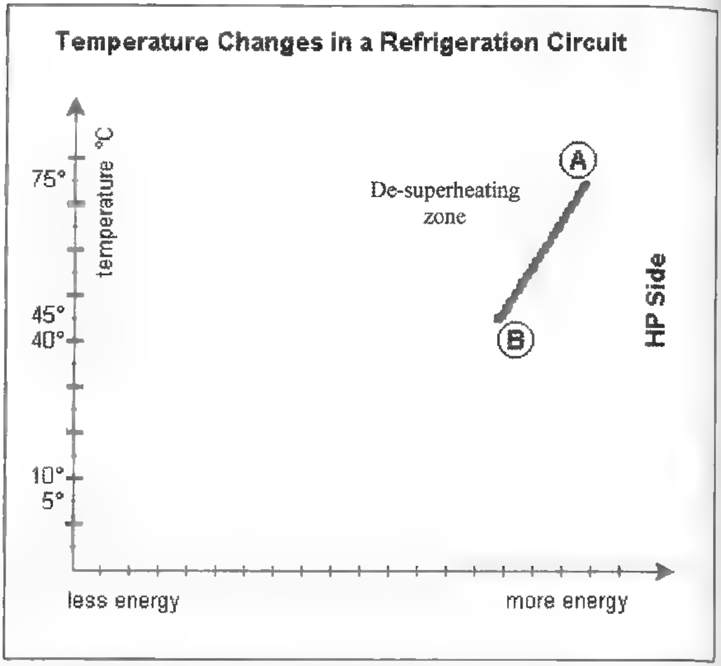
As the temperature drop that occurs as the refrigerant loses energy can be 'sensed', then this must be sensible heat.

That's right.

The gaseous R22 releases sensible heat as its temperature decreases.

Between A and B, the temperature of the superheated vapour gradually falls.

Its temperature will continue to fall until it reaches the condensation temperature.




**As it enters the condenser, the gaseous superheated refrigerant crosses the de-superheating zone where it is brought to condensation temperature.**

**<u>Point B:</u>**

After the vapour has passed through the de-superheating zone, it reaches point B at *exactly 45°C*, that is, the temperature at which condensation occurs.

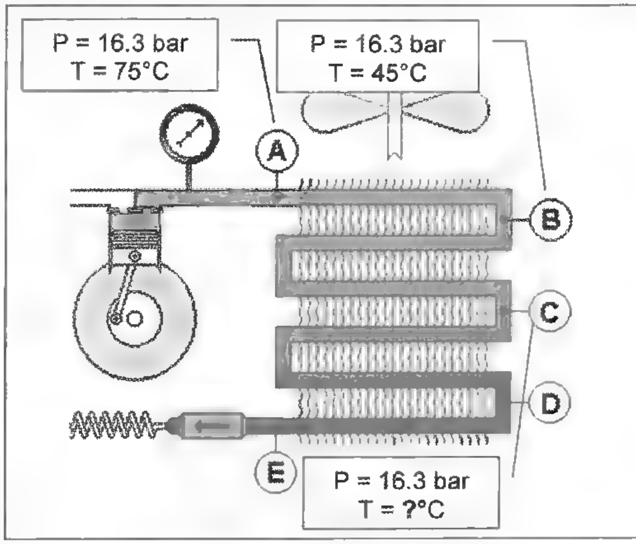
But if this vapour at 16.3 bar and 45°C were to lose a little more energy (that is, if it released a little more heat), what will happen?

At point B in the condenser, the slightest loss of additional energy will immediately lead to condensation, and the first droplets of liquid R22 begin to appear.

***Do you remember? The gauge told us that at 16.3 bar the equivalent condensation temperature was 45°C!***

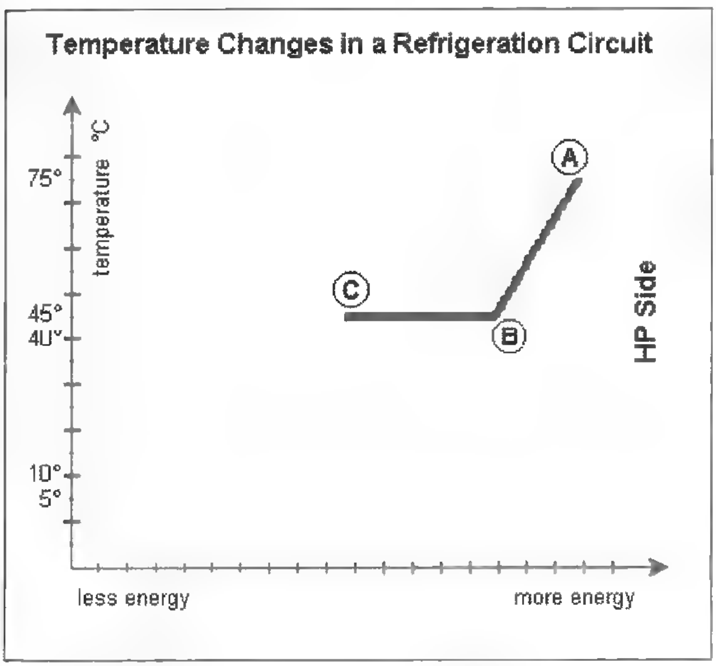
Point B is in fact a theoretical point that marks the frontier between the de-superheating zone (in which there is 100% vapour), and the condensation zone (in which there is a mixture of liquid and vapour).

## From Point B to Point C:




From point B on, the refrigerant starts to condense. That is, it changes its physical state, passing from the gaseous state to the liquid state.

As cool air continually sweeps over the condenser, the refrigerant keeps losing energy and condensation continues to take place. *As it gradually passes through the condenser, the refrigerant continues to condense, and there is more and more liquid produced (and, of course, less and less vapour remains).*




The pressure is at a constant 16.3 bar. All of the heat released from the refrigerant here results from the change of state (and is therefore latent heat).

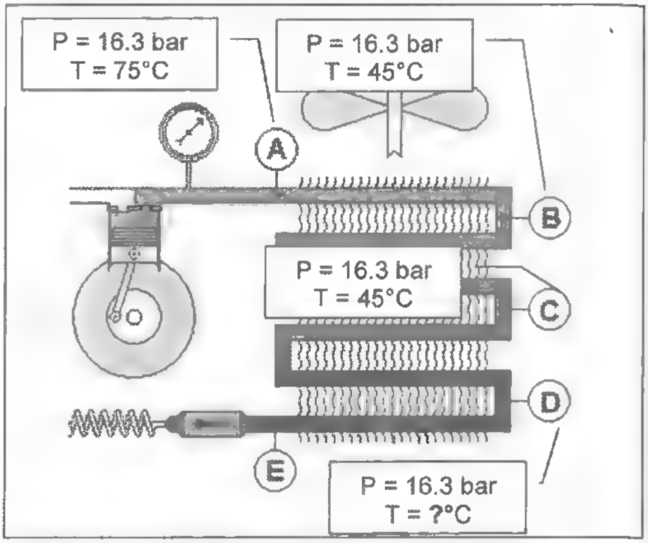
Since we now find ourselves at the condensation step, the temperature of the liquid-vapour mixture at this point remains at a constant 45°C.

**This is why a thermometer used to measure the temperature of an end piece at the middle part of the condenser, at point C say, would read 45°C.**

In refrigeration engineering terminology, this mixture of liquid and vapour is called **saturated vapour**. On the HP side, this mixture exists entirely at the condensation step. This, therefore, is the area where the pressure- temperature relationship for R22 indicated on the gauge is valid (16.3 bar and 45°C in our example).

**From point C to point D:**

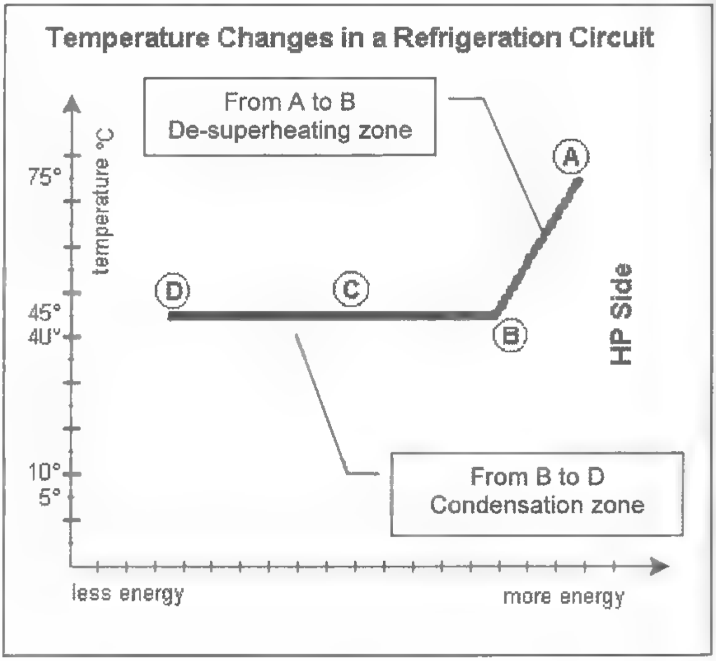
At point C, the refrigerant exists as saturated vapour. It is a mixture of liquid and vapour at 45°C and 16.3 bar.




As it gradually passes towards point D, more and more condensation occurs. There is more and more liquid present and less and less vapour.

Note that after point B (where very first droplets of liquid appear) the refrigerant is in the form of a saturated vapour, on the condensation step at 45°C.

The condensation zone ends at the precise point where the last molecule of vapour condenses. Here, there is no more vapour left, and 100% of the R22 is in the liquid state.




This is precisely what happens at point D: the last molecule of vapour condenses and there is therefore 100% of liquid R22.

We clearly see from the graph opposite that during the whole period of the condensation step that is occurring between B and D, the refrigerant loses energy in the form of latent heat.

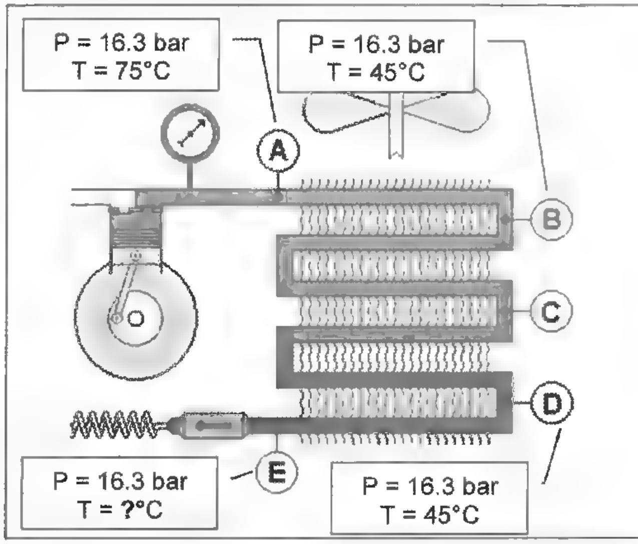
Once more, let's remind ourselves that the temperature remains absolutely constant for the entire duration of the condensation step (at 45°C in our example).

**From point D to point E:**

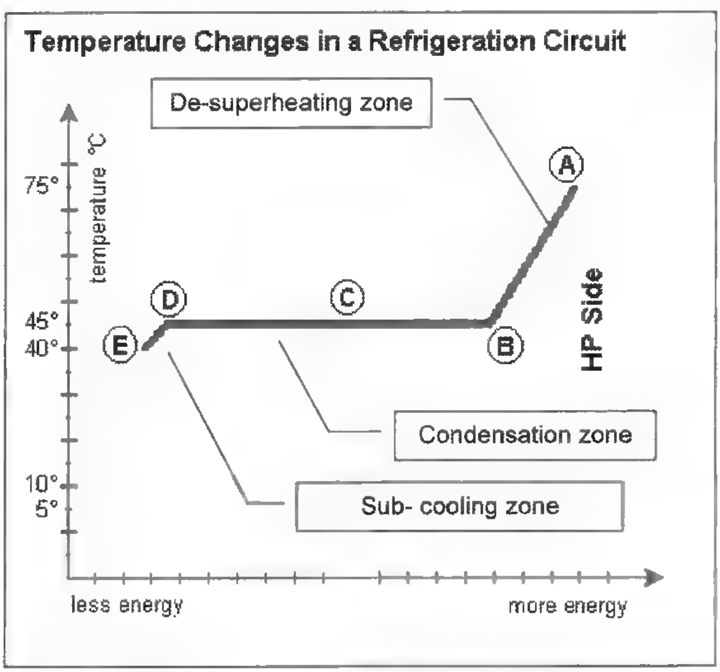
At point D, the last molecule of refrigerant vapour has just condensed. There is therefore 100% of liquid R22 at 45°C and 16.3 bar.

But since cool air is still being swept across the condenser, it continues to remove heat from the liquid R22.

Since the refrigerant is now 100% liquid, the heat that is being removed can only be sensible heat, and its temperature will decrease.




At point E, which is at the condenser outlet, the liquid refrigerant will therefore be at a temperature below that of the condensation temperature $T_k$ (for example, at 40°C). In refrigeration terminology, this is called **sub-cooled liquid.** This indicates that the liquid is at a temperature below that of the condensation step, i.e. below $T_k$.



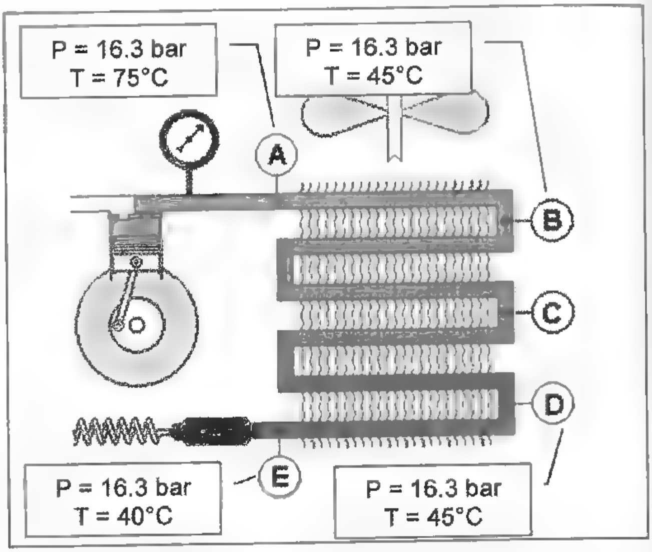

The difference between the condensation temperature and that of the liquid at the condenser outlet is called **sub-cooling.**

The zone between points D and E where this occurs is called the **sub-cooling zone**

When the liquid is sub- cooled at the condenser outlet, it is absolutely certain that there is 100% liquid in the pipe. Sub cooling is therefore a very important diagnostic indicator when there is a fault. We'll say more about this later on!

We'll see later how to measure and interpret the sub- cooling value. For now, the main thing is that we understand what it represents.

**A summary of the refrigerant's role in the operation of the condenser:**




The gauge located at the compressor discharge reads 16.3 bar. This pressure is the same at every point in the HP circuit.

The HP gauge also indicates 45°C on the temperature scale for R22. This simply means that the condensation step occurs at 45°C.

__Point A:__ R22 vapour, superheated to about 75°C, leaves the compressor outlet and enters the condenser at a pressure of 16.3 bar.

__Between A and B:__ The vapour de-superheats from 75 to 45°C at a constant pressure.

__Point B:__ The first droplets of liquid R22 appear. The temperature is equal to 45°C and the pressure is still around 16.3 bar.

__Between B and D:__ The R22 vapour continues to condense. Gradually, as the mixture of liquid and vapour approaches point D, there is *more and more liquid produced*, and there is *less and less vapour* present. The pressure and temperature stay absolutely constant at 16.3 bar and 45°C.

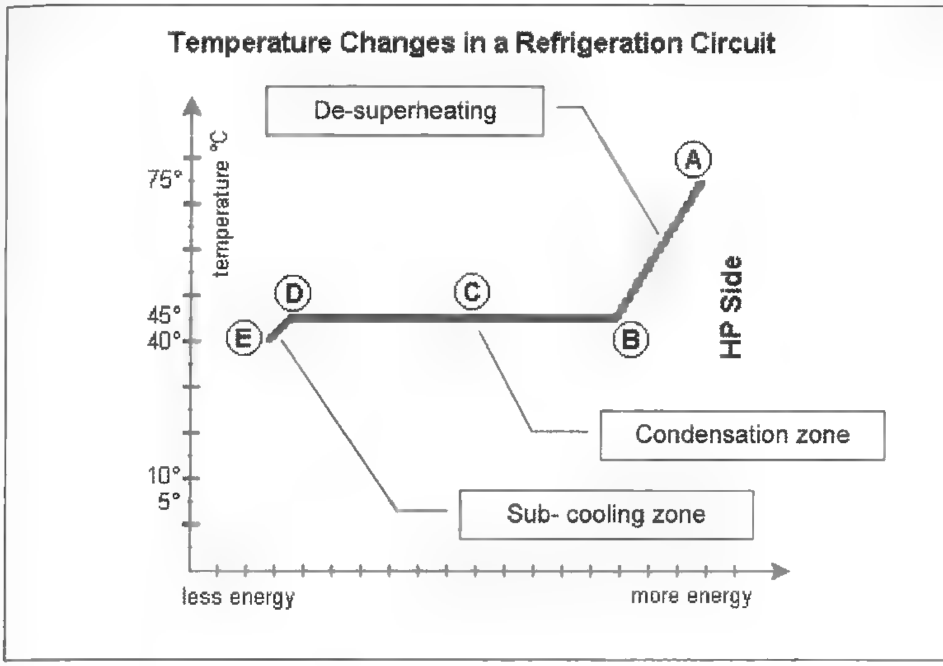
***You should note that if we place a thermometer at point C, close to the middle of the condenser, the temperature measured would correspond to the condensation temperature (that is, 45°C in our example).***

__Point D:__ The last molecule of vapour condenses at 45°C and 16.3 bar. There is *exactly* 100% liquid and the condensation step is complete.

__Between D and E:__ As the R22 is entirely in the liquid state, it is sub- cooled by the air passing over the condenser. This is the sub- cooling zone.

__Point E:__ At the compressor outlet, the pressure is still around 16.3 bar, but the temperature of the liquid is, say, 40°C. We say, then, that the liquid is sub- cooled by 45 - 40 = 5°C.

The changes to the R22 that occur in the condenser can also be represented as follows:




**<u>From A to B:</u>** there is 100% vapour which de- superheats from 75°C to 45°C (A-B is the de- superheating zone of the condenser).

**<u>At point B:</u>** the first droplets of liquid appear.

**<u>From B to D:</u>** there exists a mixture of liquid and vapour at 45°C and 16.3 bar. This mixture is called saturated vapour (B-D is the condensation zone of the condenser).

**<u>At point D:</u>** the last molecule of vapour condenses. There is, therefore, 100% liquid refrigerant.

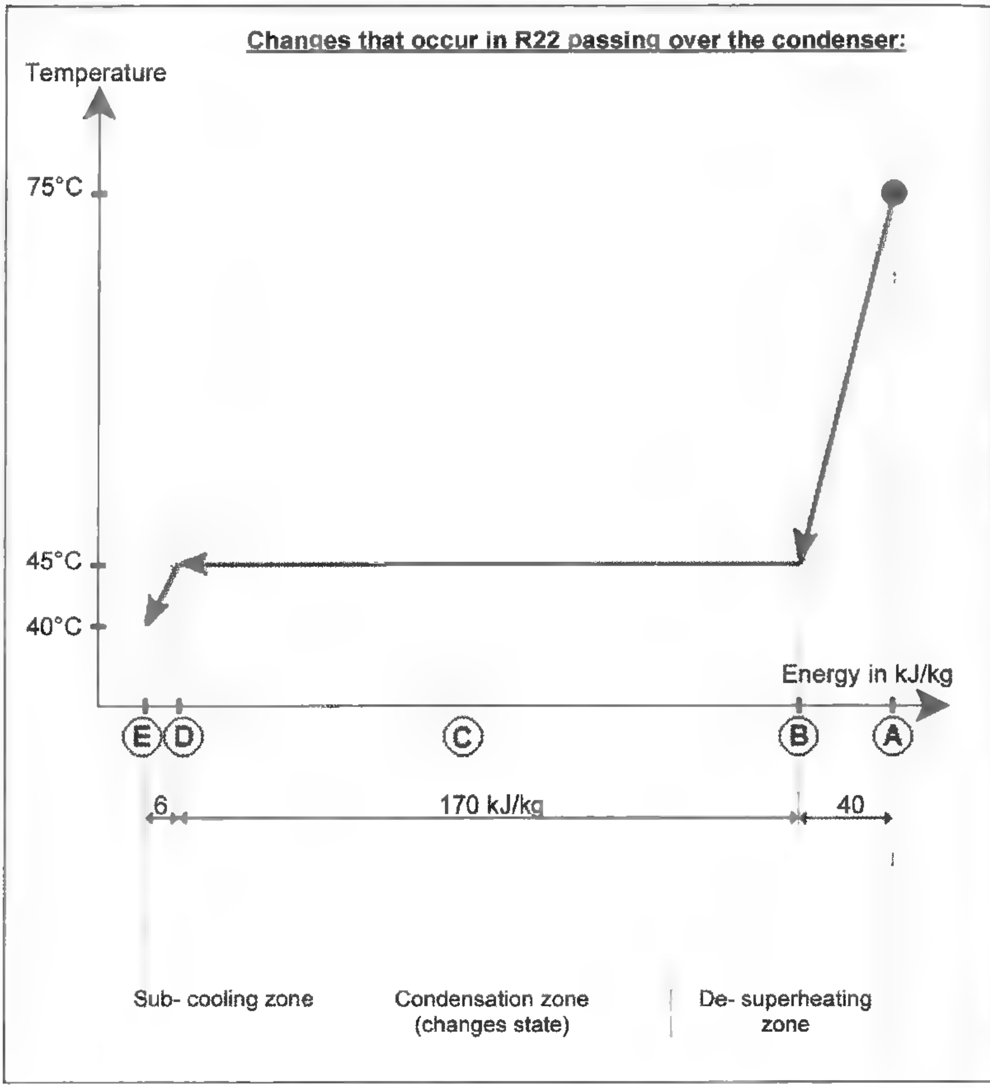
**<u>From D to E:</u>** in this zone, which is found at the bottom of the condenser, sub cooling of the liquid from 45°C to 40°C occurs. (D-E is the sub- cooling zone of the condenser).

Refrigerant enters the condenser at 75°C and emerges at 40°C. Throughout this period the pressure and temperature readings on the gauge stay absolutely constant at 16.3 bar and 45°C.

***Above all, don't forget that the temperature shown on the gauge only ever indicates the condensation temperature.***

## Now lets look at what happens to the air at the condenser.

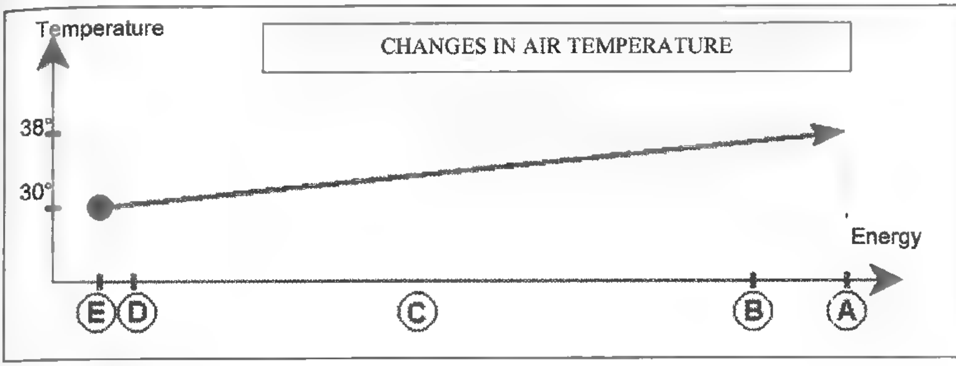
Firstly, the diagram below should give you a fair idea of the different amounts of energy that the refrigerant releases to the air as it passes over the condenser.



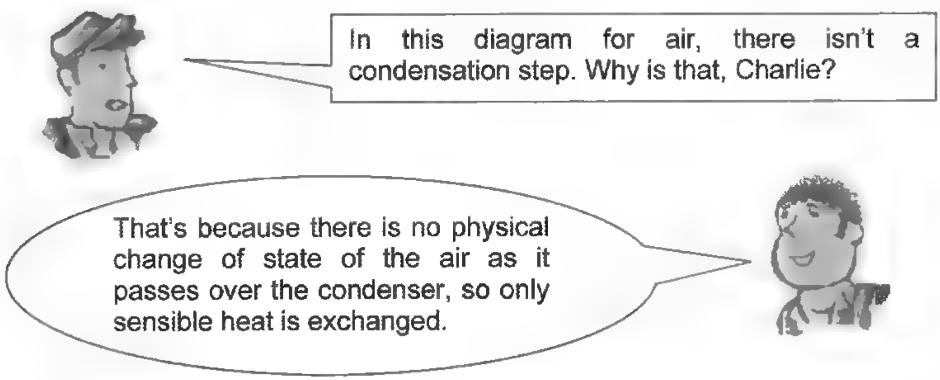

You can see that 40 kJ of energy must be removed to de- superheat 1 kg of R22 from 75 to 45°C (between A and B). Only 6 kJ needs to be removed to sub- cool 1 kg of liquid by 5°C (between D and E), but 170 kJ needs to be removed to condense 1 kg of refrigerant between B and D! The capacity of the condenser used for condensation alone (at constant temperature) represents close to 80% of its total capacity. This also means that close to 80% of the condenser volume contains saturated vapour at 45°C.

***These figures explain why the condensation temperature is used as the reference temperature for the HP side.***

Now, if we examine the graph below, we'll observe that the energy released by the refrigerant is absorbed entirely by the air that passes over the condenser.



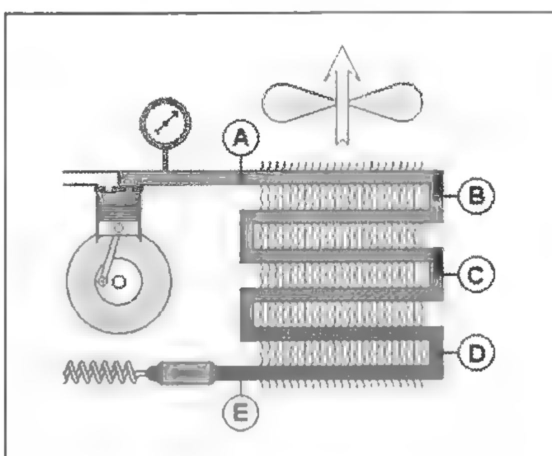

The refrigerant releases most of its heat between B and D (the condensation zone): therefore this is where the air is heated the most!



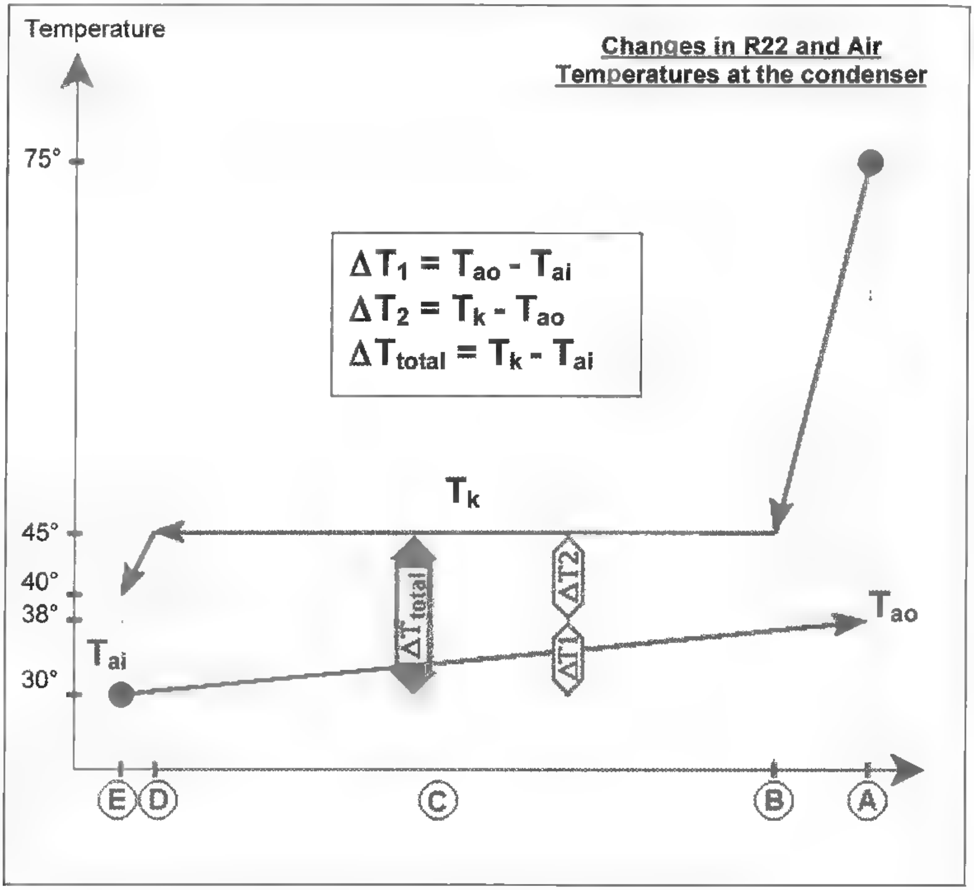

Charlie is quite correct. The temperature of the air gradually increases as it passes over the condenser, from 30°C as it enters the condenser to 38°C as is emerges from the condenser.

Note also that the coldest air enters the condenser from the side where point E is found, and then passes towards point A. The air and the refrigerant are in a counter- current flow.

*Remember that for a given cooling capacity, counter-current flow allows a significant reduction in the condenser size.*



We can also examine counter- current flow using the diagram below. Note that the refrigerant enters at A and then emerges at E, whilst the air passes in the opposite direction. Let's look at the *temperature differences* involved.




The temperatures of interest to us are:

- $T_k$: Condensation Temperature of the refrigerant.
- $T_{ai}$: Temperature of **a**ir at the condenser **i**nlet.
- $T_{ao}$: Temperature of **a**ir at the condenser **o**utlet.

Note that temperature differences are represented by **ΔT** (*delta T*). In our example, we can see that:

- $\Delta T_1 = T_{ao} - T_{ai}$ that is, the air outlet temperature – the air inlet temperature. This ΔT has a value here of 38 – 30 = 8°C.

- $\Delta T_2 = T_k - T_{ao}$ that is, the condensation temperature – the air outlet temperature. This ΔT has a value here of 45 – 38 = 7°C.

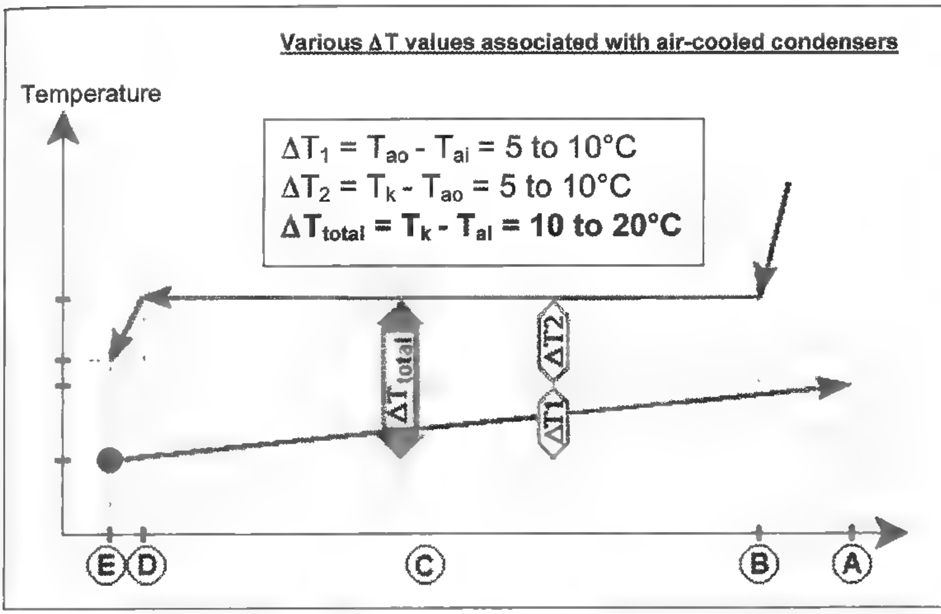
- $\Delta T_{total} = T_k - T_{ai}$ that is, the condensation temperature – air inlet temperature. This ΔT has a value here of 45 – 30 = 15°C

*In general, for common comfort air conditioning systems, we find:*

- A temperature difference between the air inlet and air outlet of between 5 and 10°C.
- A temperature difference between the air outlet temperature and the condensation temperature that is also between 5 and10°C.

***Finally, for $\Delta T_{total}$, which is by far the most interesting,***

- **A temperature difference between the air inlet and the condensation temperature that is, therefore, between 10 and 20°C.**





But why should $\Delta T_{total}$ be the most important value?

*Quite simply because it's extremely easy to measure the external temperature.* If, say, we have an average $\Delta T_{total}$ at the condenser of about 15°C, ***then if it's 30°C outside, I can expect a condensation temperature ($T_k$) of about 45°C!***

So, when I connect my HP gauge, the condensation temperature should be about 45°C. If the gauge reading is *a lot higher or a lot lower* than this, then I immediately know that there's a problem!

So if I understand this correctly, the condensation pressure (that is, the HP value) depends on the temperature of the air at the inlet to the condenser. In our example, it's 30°C outside, and so 30°C at the condenser inlet. That's why there is condensation at 30 + 15 = 45°C.

***The gauge reads 45°C, and as there is R22 in the system, the needle shows the pressure temperature relationship of this refrigerant and therefore a pressure of 16.3 bar!***

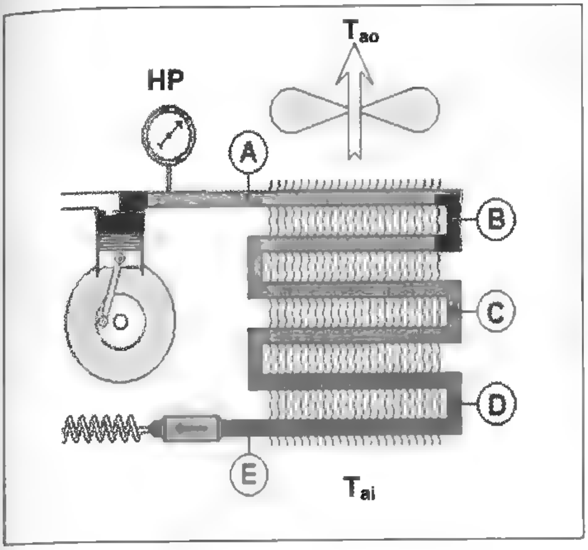
That's it, Charlie, you've got it! The HP value depends directly on the external temperature and on the $\Delta T_{total}$ value at the condenser. In our example, when the external temperature is 25°C, the condensation takes place at 25 + 15 = 40°C.

On the other hand, if it's 40°C outside, then the condensation occurs at 40 + 15 = 55°C. Is that right?

***Absolutely right!* In both these cases, as a $\Delta T_{total}$ of 15°C at the condenser is perfectly correct, the HP value will be as expected.**

We've just seen the essentials of how an air-cooled condenser operates, and you should be able to understand everything that's been discussed before we continue. To help you with this, we're now going to do a little exercise that will enable you to decide for yourself exactly how well you've understood the subject...

On the installation below, several temperature readings have been made. Your task is to work out the missing values in order to complete the two tables.



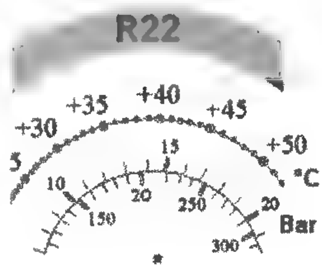

External temperature: **25°C**

$\Delta T_{total}$ at the condenser: **15°C**

$\Delta T$ of the air: **7°C**

Sub- cooling: **5°C**

To help you, here is the gauge used:




*Now it's up to you to complete the entries in the first table:*

| $T_{ai}$ °C | $T_{ao}$ °C | $\Delta T$ total °C | $T_k$ °C | HP bar |
|---|---|---|---|---|
| **25°C** | | **15°C** | | |

*Now complete the second table:*

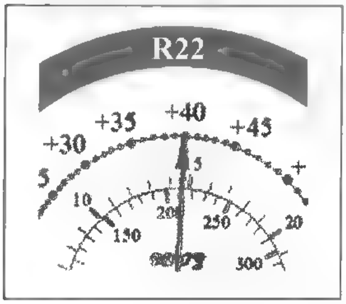
| Point | A | B | C | D | E |
|---|---|---|---|---|---|
| T in °C | **70°C** | | | | |
| P in bar | | | | | |
| State *(see below)* | | | | | |

*State:* put **V** if the refrigerant is as superheated **V**apour, **L** if it is a sub-cooled **L**iquid and **SV** if it is in a **S**aturated **V**apour state.

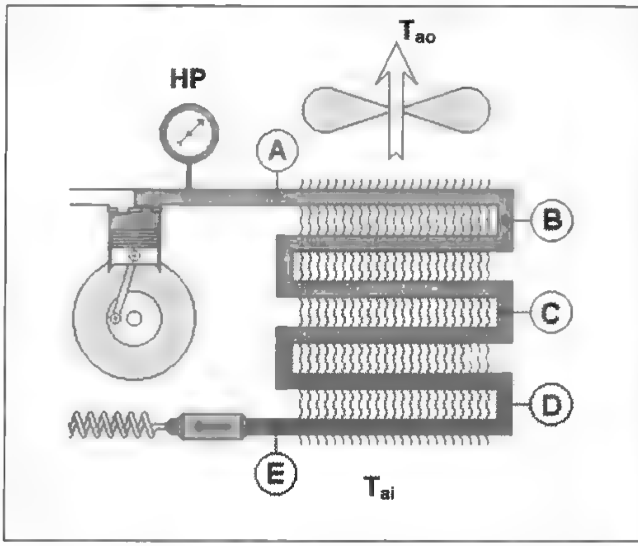
*Try this yourself to see if you really understand this before you look at the solutions on the next page…*

## Solutions to the Exercise:

| $T_{ai}$ °C | $T_{ao}$ °C | $\Delta T_{total}$ °C | $T_k$ °C | HP bar |
|---|---|---|---|---|
| **25°C** | 32°C | **15°C** | 40°C | 14.5 bar |




- $T_{ao} = T_{ai} + \Delta T$ for the air = 25 + 7 = 32°C.
- $T_k = T_{ai} + \Delta T_{total}$ = 25 + 15 = 40°C.
- HP value: as the needle of the HP gauge is showing the value of $T_k$ (that is, 40°C), we can see that it is showing us a pressure of about 14.5 bar at the same time.




• **At point A,** the R22 exists as superheated vapour (so there is 100% vapour) and its temperature is 70°C.

*The pressure is at 14.5 bar and it will be equal to this value at every point (and therefore at B, C, D, and E) throughout the HP side).*

• **At point B,** the vapour will have been de- superheated, until its temperature reaches the temperature corresponding to the condensation step, that is, 40°C. At this point, the first liquid droplets will have appeared, and the condensation step starts. Throughout the rest of the condensation step, (that is from B to D), the refrigerant will remain in the form of a saturated vapour at 40°C.

• At point **C**, right in the middle of the condenser, the R22 is still on the condensation step; that is, it exists as a saturated vapour at 40°C.

• At point **D**, the R22 has completed the condensation step, and the last molecule of vapour condenses at 40°C and 14.5 bar.

• At point **E**, the liquid R22 is sub cooled by 5°C between D and E. Its temperature is equal to the condensation temperature $T_k$ minus the sub- cooling value, that is: 40 - 5 = 35°C. The pressure has remained constant from the start at 14.5 bar.

*So we can turn to the other table, which you should have completed like this:*

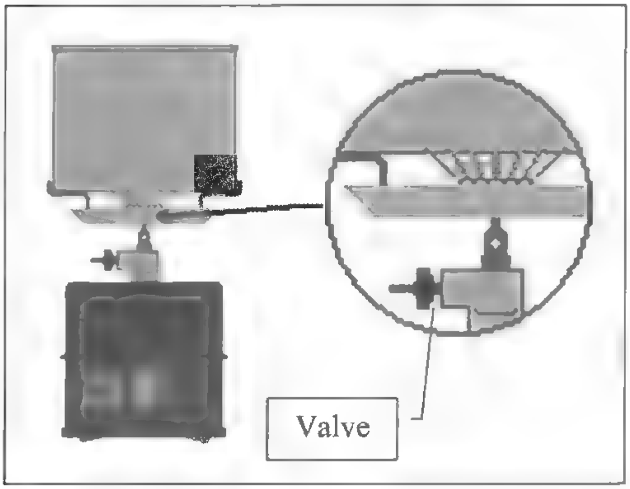
| Point | A | B | C | D | E |
|---|---|---|---|---|---|
| T in °C | **70°C** | 40°C | 40°C | 40°C | 35°C |
| P in bar | 14.5 bar | 14.5 bar | 14.5 bar | 14.5 bar | 14.5 bar |
| State | V | SV | SV | SV | L |

The sub- cooled liquid refrigerant leaving the condenser via. the liquid line now arrives, at high pressure, at the inlet of the capillary expansion device.

If you've understood the exercise that we've just worked through, we can now move on to a more detailed study of this type of expansion device.

# THE CAPILLARY EXPANSION DEVICE: NORMAL OPERATION

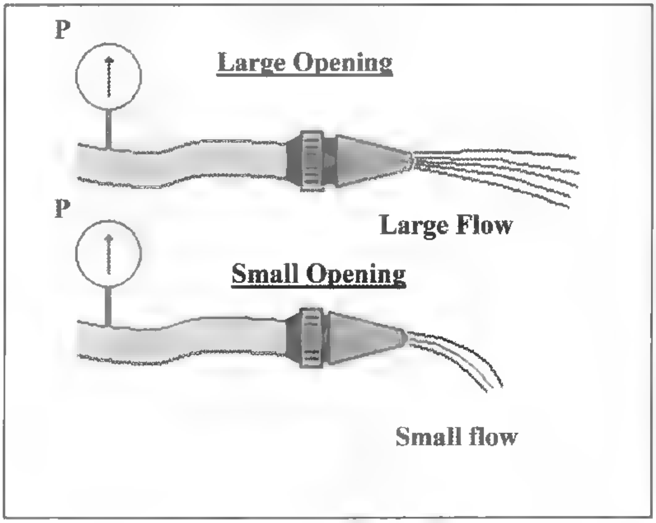
Comfort A/C systems are equipped with an expansion device known as a "capillary". This device is manufactured from a length of copper tube of very small diameter, from which it takes its name. But this simple piece of tubing has an essential role, as it maintains a precise flow of refrigerant throughout the system. Its properties should never be modified. In spite of its small size, this expansion device is just as essential as the compressor, condenser or evaporator.




The capillary has the same role as the valve of a camping- gas stove. The size of the flame depends on the opening of the gas valve, that is to say, on the resistance provided by this valve to the passage of butane from the cylinder.

If we open the valve more, the resistance is lowered. More gas passes and the flame becomes larger.

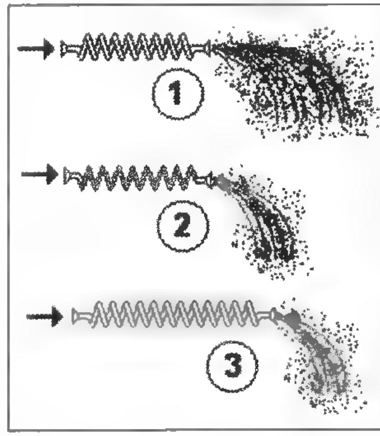
The same thing happens with a garden hose. The more we open the nozzle, the smaller is the resistance and the larger is the flow of water.




*In a refrigeration system, we see exactly the same type of effect happening.*

The flow of liquid through the expansion device depends, in a similar way, on the resistance of the capillary to the flow of the refrigerant.

As far as the capillary is concerned, the situation is exactly the same. The flow of liquid refrigerant through it depends on the resistance that it offers to the passage of the refrigerant. But in contrast to the nozzle of a garden hose, the capillary is not adjustable. It is simply a long and very narrow piece of copper tubing.

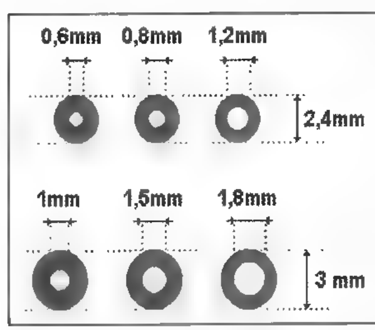



**The resistance of the capillary depends on its diameter.** Both capillaries 1 and 2 are of exactly the same length, but the diameter of 2 is much smaller. Since its' resistance to the passage of refrigerant is greater, the flow through it is smaller.

**The resistance of the capillary depends on its length.** Both capillaries 1 and 3 have exactly the same diameter, but 3 is much longer. Since its' resistance to the passage of fluid is larger, the flow through it is smaller.

**When a manufacturer installs a capillary in a piece of equipment, he has very carefully established the length and diameter required to produce a specific flow of refrigerant. But be careful! If you have a problem, *don't think that all you have to do is measure the length and diameter of a capillary in order to obtain an identical replacement!***

Anyone who has ever tried to measure the exact diameter of a capillary quickly realises that without specialist measuring equipment all you can actually measure is the external diameter, and then *often only approximately*. Things then start to become complicated, as there are at least a dozen different internal diameters between 0.66 and 2.29 mm available, as well as dozen or more external diameters for capillaries, from 1.83 up to 4.76 mm! *And the complications involved don't end here, because for the same external diameter there could be several possible internal diameters!*

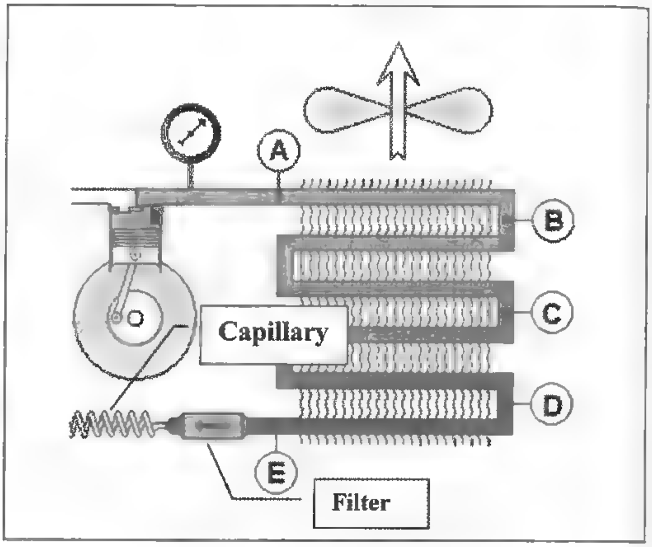



You only have to leaf through the catalogues from the various refrigeration equipment distributors to see the many types of capillary tubing available. For example, one with an external diameter of 2.4 mm can have an internal diameter of 0.6 mm, 0.8 mm *or* 1.2 mm. Similarly, for an external diameter of 3 mm, there are capillaries with internal diameters of either 1mm, 1.5 mm *or* 1.8 mm.

**There is a lesson to be learned here: if you should ever need to replace a capillary, it's better to buy a manufacturer's original part. *You'll avoid a lot of trouble that way!***

The internal diameter of a capillary tube is always very small (0.6 mm for example). *This is the narrowest point in a refrigeration circuit.*

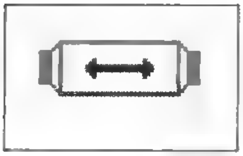
It's here, therefore, that any contaminants that may be present (copper turnings, grit from abrasives or dust from brazing etc.) are likely to cause an obstruction in the system. This could hinder or even block the flow of refrigerant, and so prevent the operation of the air conditioning system.




To prevent this, manufacturers of equipment routinely install a filter before the inlet of the expansion device.

In this way, any possible impurities remain trapped in the filter, and won't cause an obstruction in the capillary.

**Note:** filters normally have an arrow to show the refrigerant flow direction. Always install the filter the correct way.



Some filters have a double- ended arrow marked on them, as shown opposite. Refrigerant can flow through these in both directions without causing any problems (this type of bi-directional filter is mostly used in heat pumps).

*But whatever their design, filters have another essential role.* They all act in practice as *filter- dryers.*

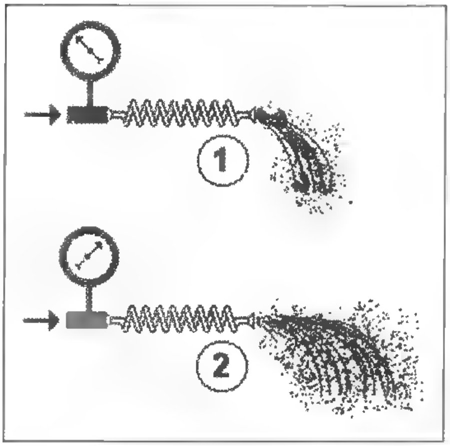
Their second function then is to *dehydrate* the refrigerant, that is, to remove any moisture that may be present in the refrigeration circuit. *Water, even in minute quantities, is a refrigeration system's No.1 enemy (and therefore yours, too!).*

Water and refrigerant can form powerful acids. These will cause oil to lose its lubricant properties, and can attack the insulation lacquer on the electrical windings of the compressor motor. When this happens, motor burn out soon follows, as do numerous other problems.

*But let's get back to the capillary.* We've seen that the flow of refrigerant that it will allow depends on its length (the longer it is the less refrigerant flows through it), and its internal diameter (the smaller its diameter the less refrigerant flows through it).

*Can you see another factor that could affect the flow?*

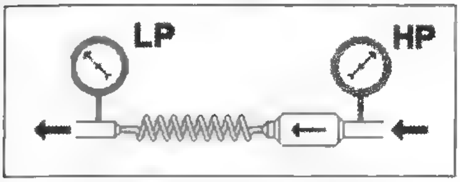
Let's take two capillaries of precisely the same length and the same internal diameter.




In case 1 opposite, the pressure at the inlet to the capillary is quite low. The flow of refrigerant emerging from it is also low.

In case 2, the pressure at the inlet to the capillary is much greater. Since the force pushing the liquid through the tube is larger, it's easy to see why the refrigerant flow is much greater than in the first case.

*We've just observed a very important principle: refrigerant flow also varies with the pressure at the capillary inlet.* To be precise, the flow is a function of the pressure difference between the inlet and outlet of the capillary.




The flow of refrigerant through the capillary depends, then, on the dimensions of the capillary used (its internal diameter and its length). It also depends on the pressure difference between the inlet and the outlet of the expansion device, **that is, the difference between HP and LP**.

**Refrigerant flow and therefore cooling capacity depends on two factors: the dimensions of the expansion device, and the pressure difference between the inlet and outlet of the expansion device.**

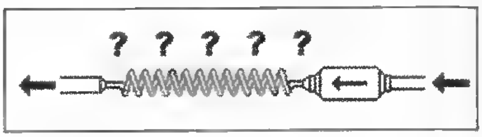
*But do you know what determines the expansion device inlet and outlet pressures?*

I know that at the capillary inlet the pressure is HP. I remember that HP depends upon the air temperature at the condenser air inlet and on $\Delta T_{total}$ for the condenser (I know that this is about 15 °C). But I don't know about the LP...

That's quite right, HP does depend on $\Delta T_{total}$ for the condenser, and also on the external temperature. You'll see in the next chapter that LP depends on the internal temperature, but everything in its own time...

We should remind ourselves again that the selection of a capillary expansion device isn't straightforward. Nevertheless we might have to replace one, for example, if it becomes blocked. If this happens, we could always try to unblock it first.

But where is the obstruction likely to be? *If you don't have a capillary cleaner at your disposal* (a manual pump that injects oil into the capillary at high pressure), you could blow nitrogen through it in the opposite direction to the flow. You could also shorten the capillary *by a few centimetres on the inlet side*, and, hoping that the obstruction is there, remove it this way (take care: the resistance of the capillary depends on its length, and you should never shorten it too much).



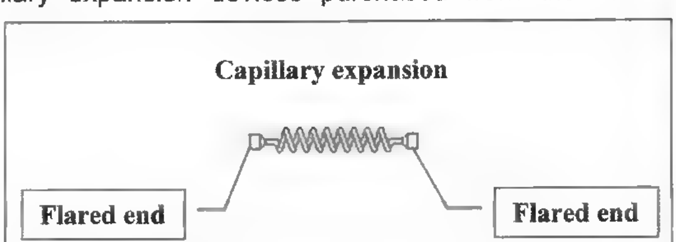

Unfortunately, this doesn't succeed very often, and you may have to change the capillary and the filter- dryer anyway (if the filter dryer had done its job properly, the capillary wouldn't be blocked in any case)

**If you have a genuine replacement capillary, supplied by the manufacturer of the faulty equipment, and of the same model as the blocked capillary, then replacement is a relatively simple operation.**

*Remember that if you try to fabricate a replacement capillary yourself it can often result in a series of problems.*

The best solution is to **make a note of the exact details of the equipment** in question and to **order the appropriate capillary** from your refrigeration equipment supplier.

In addition, capillary expansion devices purchased from the manufacturer are often provided with two flared ends. These make fitting easier, and also eliminate any blocking of the tube due to brazing.

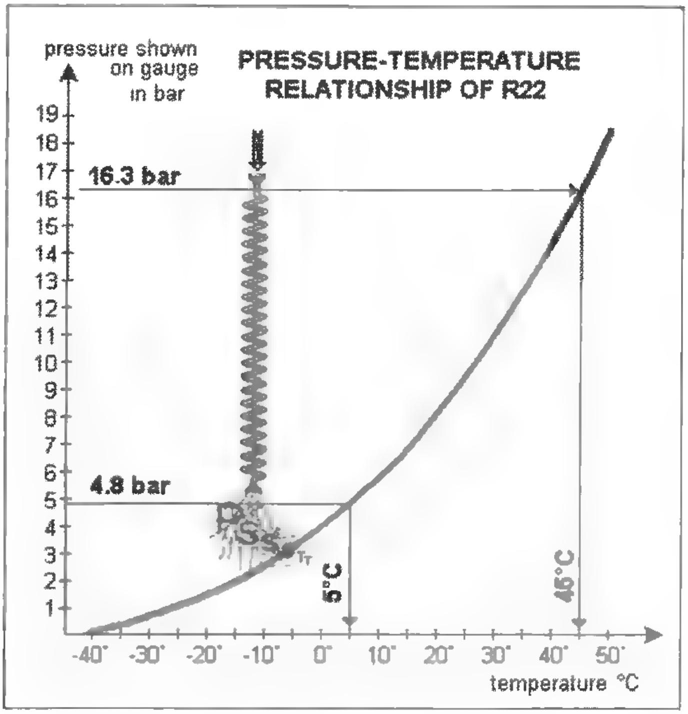


We've just seen how the refrigerant flow in a capillary expansion device changes according to its dimensions and the HP and LP pressure values. But what exactly happens to the refrigerant itself as its pressure drops sharply between the inlet and the outlet of the capillary?

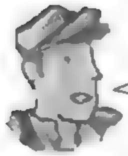
The expansion of a refrigerant is exactly the opposite of compression. We've seen that during its compression R22 heats up. During its expansion it cools.

The length and diameter specified by the manufacturer cause a specific pressure difference to exist across the capillary.

For example, a pressure of 16.3 bar at the inlet might fall to 4.8 bar at the outlet.

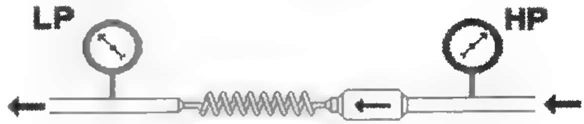



OK, and since the pressure is only 4.8 bar, is the refrigerant liquid at 5°C as shown by the pressure temperature relationship for R22?



That's correct, but to cool the liquid R22 from 45°C to 5°C, heat ***must*** be removed from the liquid. *That's why close to 20% of the liquid refrigerant vaporises as it passes through the expansion device.*

***It's the heat that's lost by vaporising this 20% of the liquid refrigerant that causes the temperature of the refrigerant to drop as it passes through the capillary.***




**4.8 bar**
**5°C**

*about*
**20% vapour**
and **80% liquid**

**16.3 bar**
**45°C**

0% vapour
**100% liquid**

In summary, then, the capillary expansion device is a type of 'lift' that allows the refrigerant to descend from the HP level to the LP level. The refrigerant enters the capillary as *HP sub-cooled liquid*, and emerges as *saturated LP vapour*.

So the pressure drop causes part of the liquid refrigerant to evaporate. *The liquid uses its own heat to evaporate, and this causes it to cool.* If you think about it, the refrigerant wouldn't cool from 45°C to 5°C just by magic, would it!

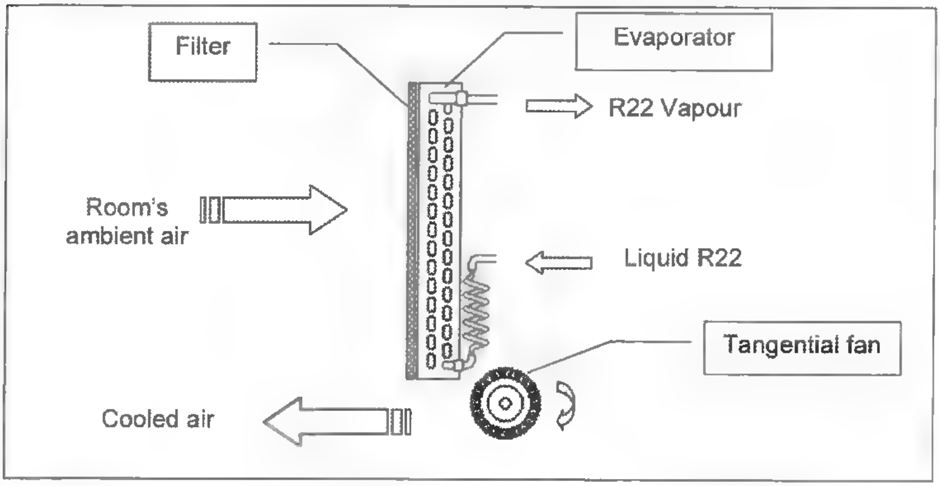
In all cases, if the air temperature at the condenser or evaporator inlet changes, the LP and HP with also change. These changes mean that the refrigerant flow and therefore the refrigerating capacity of the equipment will change.

To avoid these sort of problems, it's essential that we observe the restrictions in operating conditions laid down by the manufacturer. If we don't do this, we risk invalidating the manufacturer's guarantee.

We'll study a typical set of manufacturer's documentation later, and we'll look then in more detail at the risks involved in failing to observe a manufacturer's instructions about operating conditions.

# THE EVAPORATOR: NORMAL OPERATION

The evaporator is a heat exchanger that operates on the same principles as the condenser. Its function is to allow the best possible exchange of heat between air of the room being air- conditioned, and the refrigerant flowing inside the equipment pipework.




The ambient air gives up its heat to the refrigerant as it passes over the evaporator. The refrigerant then vaporises as it absorbs the heat lost by the air whilst the air itself is simultaneously cooled.

Note that exactly as with the condenser, **the refrigerant and air are in counter- current flow**, so that the heat exchange is optimised.

The flow of air in the air- conditioned room is often achieved by using a tangential fan, which works on the same principle as a paddle wheel.

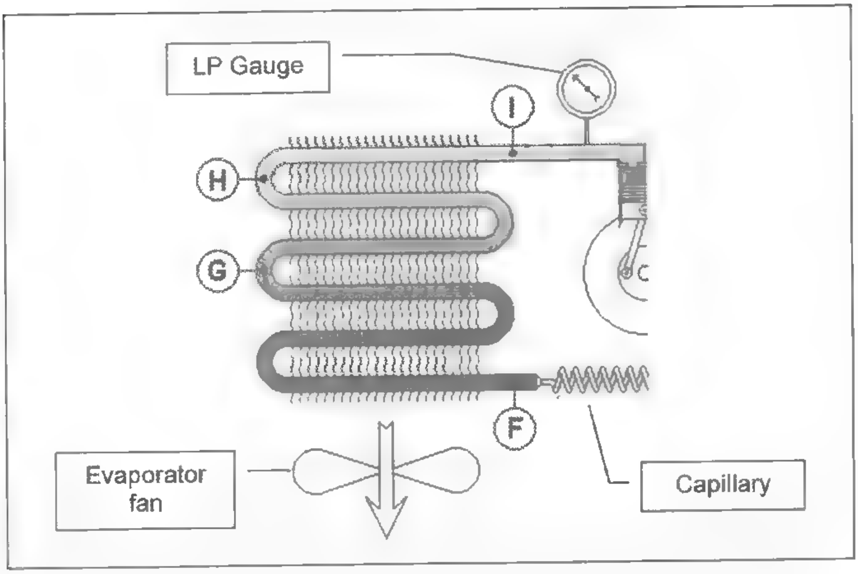
**Tangential Fan:** *Long* turbine with small *diameter*

This type of fan, with a long turbine of small diameter is particularly appropriate for comfort air-conditioning because it is very quiet.

Note that the ambient air passes through a filter before moving on over the evaporator. This filter should always be kept perfectly clean. We'll take some time to discuss this later on, but just remember for now that *a clogged up filter is the origin of numerous faults.*

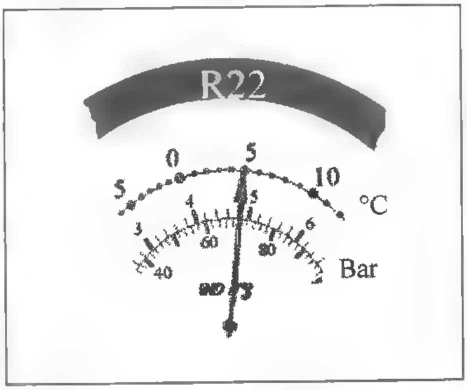
Now let's turn once more to the refrigerant...

To study how the refrigerant passes through the evaporator, we'll use the diagram and symbols below:

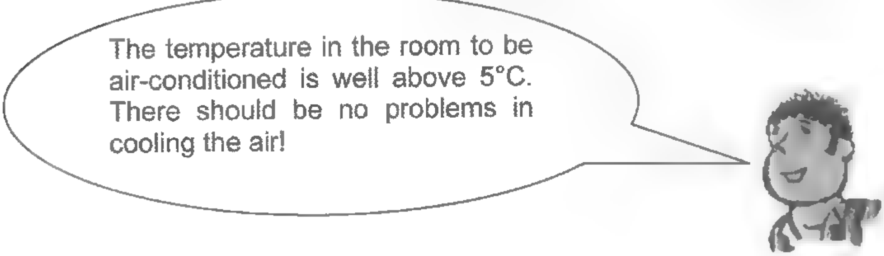



**Firstly, remember that the LP is the same at all points in the low pressure side, and that the refrigerant emerges from the capillary expansion device as saturated vapour (as a mixture of about 80% liquid and 20% vapour).**

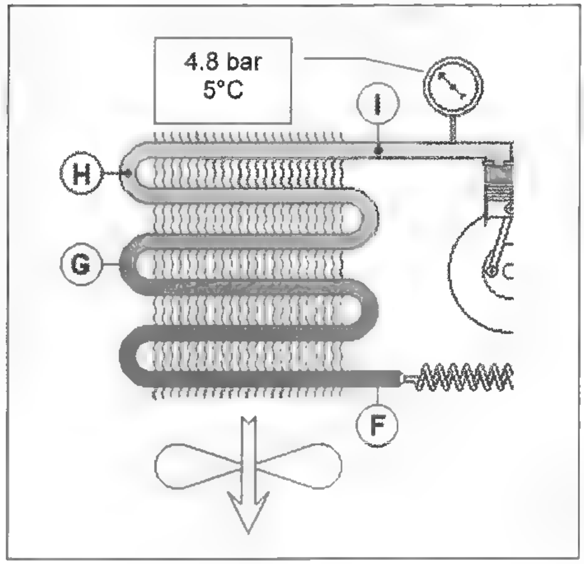
Now let's use the example that we used in the last chapter again, and assume that the LP gauge shows a pressure of 4.8 bar.




The pressure–temperature relationship for R22 marked on the gauge confirms that at a pressure of 4.8 bar, the evaporation temperature of R22 is 5°C. That is, the evaporation step takes place at this temperature.



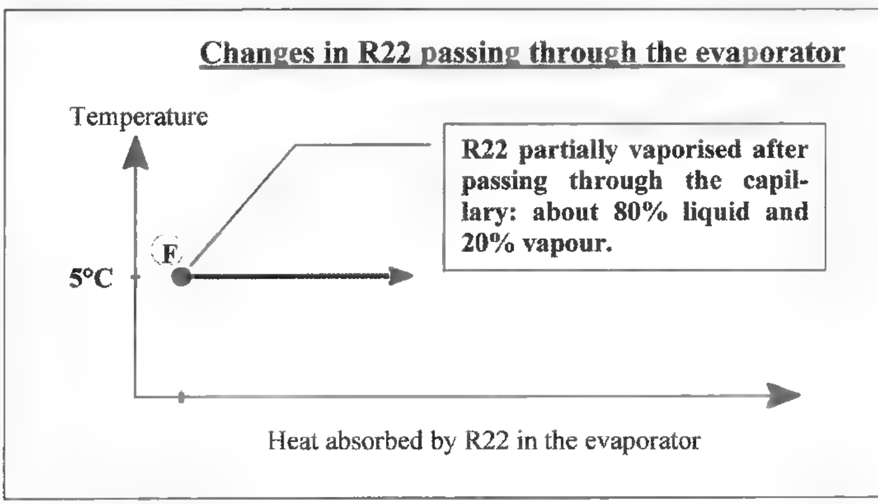
Now let's take our diagram and examine in more detail the state of the refrigerant at various points in the LP circuit.




**Point F:**

The mixture of R22 vapour and liquid emerges from the capillary expansion device at a pressure of 4.8 bar (in this example) and a temperature of 5°C.

As we did when we studied the condenser, we're going to follow the changes that take place in the refrigerant with the help of a diagram.



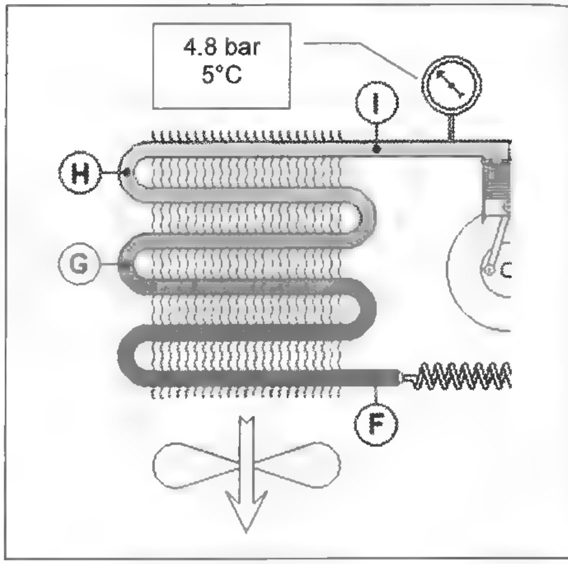

Note: Don't be too concerned about the exact percentages of liquid and vapour at the capillary outlet. This actually varies according to the operating conditions.

To simplify things as much as possible, let's say that the bigger the temperature difference between the capillary inlet and outlet is, then the colder the liquid should become. To cool the liquid any further, we must remove more heat from it, and so more liquid must then be vaporised.

**What is important to remember is that the refrigerant emerges from the capillary at low pressure and low temperature,** ready to absorb heat from any body hotter than itself, and particularly from the air of the room being air- conditioned; this is the basic aim of an air conditioning system.

## From point F to point H:

From point F to point H, the R22 is always on the evaporation step at 5°C.




Whilst flowing through the evaporator, the refrigerant at 5°C gradually absorbs heat from the room's warm air as it sweeps over the evaporator.

As the refrigerant is on the evaporation step, its temperature stays constant, and all the heat absorbed from the air is entirely used to vaporise the liquid. There is more and more vapour and less and less liquid. The air is cooled as this happens.

Let's look at point G, somewhere close to the middle of the evaporator. *What temperature do you think that a thermometer placed at this point would show?*

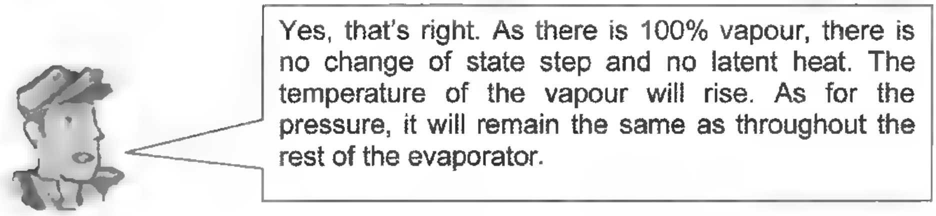
***Of course, point G is situated right in the middle of the evaporator, where the R22 is at its evaporation step. A thermometer at G would read 5°C, that is, the same temperature indicated by the LP gauge located at the suction side of the compressor.***

So as it moves along the evaporator, the refrigerant vaporises by absorbing heat from the air. So more and more vapour is produced and less and less liquid is present...

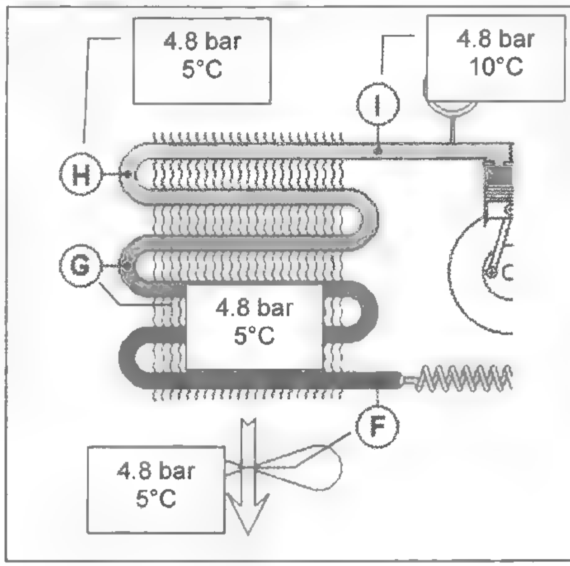
## At point H:

At point H, the last droplets of liquid now vaporise. This point, then, is right at the end of the evaporation step, and there is fully 100% vapour present at 5°C.

OK, at H there is no more liquid present, but we're not at the end of the evaporator yet. As there is still warm air passing over the evaporator, will the vapour at 5°C absorb some more heat?




**From point H to point I:**




At H, the refrigerant exists as 100% vapour at a pressure of 4.8 bar.

The air in the room is a lot warmer than the vapour, and is still passing over the evaporator, so the temperature of the vapour continues to increase until we reach point I.

As with the condenser, we can likewise talk of **superheated vapour** for this situation in the evaporator.

In this instance, the vapour is superheated relative to the evaporation temperature, which is the reference temperature for the LP side. The difference between the temperature of the refrigerant at the outlet of the evaporator and the evaporation temperature is called **the superheat**.

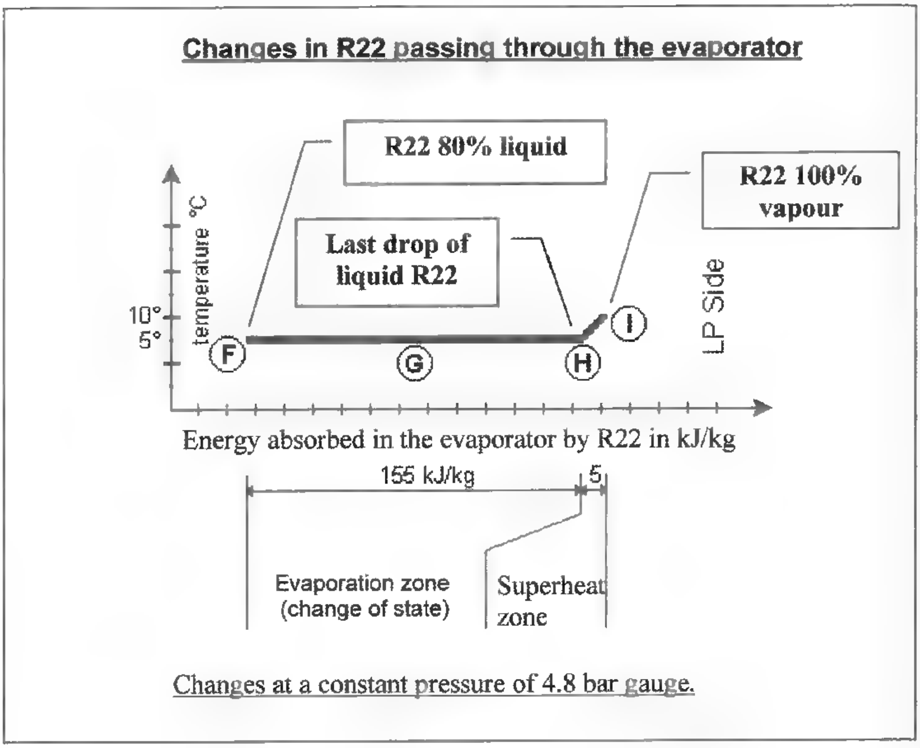
In our example, the temperature of R22 at the evaporator outlet is 10°C. The evaporation temperature is 5°C. The value of the superheat is therefore 10 – 5 = 5°C.

***From now on, remember the basic fact that vapour drawn into the compressor is superheated by several degrees.***

So, we can be certain that the compressor only ever draws in vapour, and never liquid. In fact, if liquid does reach the compressor, we'd have the problem known to refrigeration engineers as "liquid hammer" or "liquid slugging".

For now, let's just say that 'liquid hammer' results in insufficient lubrication of the compressor, and that it may even end up by purely and simply destroying the valves!

Now let's look at the diagram below which summarises the changes occurring in the refrigerant as it passes through the evaporator:




You'll notice that unlike the condenser, the evaporator isn't made up of three distinct zones, but only two: these are the evaporation zone and the superheated zone.

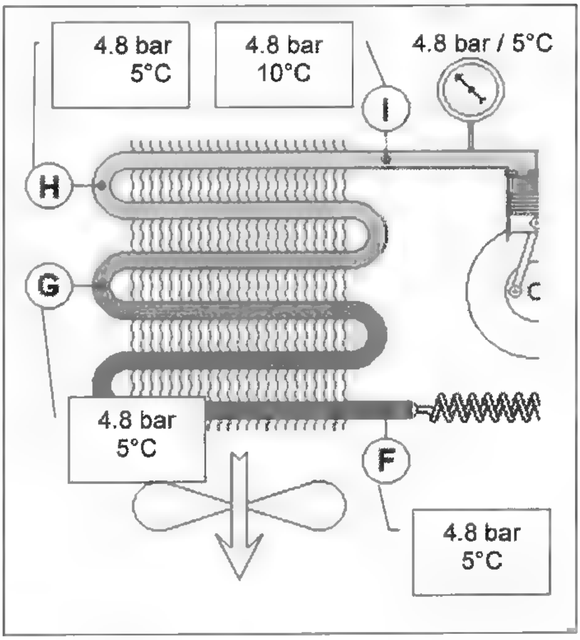
Note that in our example, with a superheat of 5°C, the superheated zone only represents about 3% of the total capacity of the evaporator, that is, only a very small proportion of it.

The superheat is very important in analysis of the performance of a refrigeration system.

***In addition, it's very easy to measure, and it's really useful in helping us know how well an air conditioning system is operating, and for diagnosing faults.***

We'll see later on how to actually interpret the value of the superheat. For now, it's important just to know what it means, and where in a system we can measure it.

## Summary of the role of the refrigerant in the evaporator:




Throughout the LP side, the pressure is constant, and it corresponds to the value shown on the gauge, that is 4.8 bar.

The pressure- temperature relationship of R22 marked on the gauge tells us that the evaporation step takes place at 5°C.

**Point F:** the refrigerant emerges from the capillary expansion device at 4.8 bar. As the expansion has caused part of the refrigerant to evaporate, there is about 80% liquid and 20% vapour present here.

**Between F and H:** The 'cold' R22 vaporises by absorbing heat from the 'warm' air sweeping over the evaporator. More and more vapour is produced, and there is less and less liquid present as the refrigerant gradually approaches point H. Since the refrigerant is on the evaporation step, the pressure and temperature stay quite constant at 4.8 bar and 5°C.

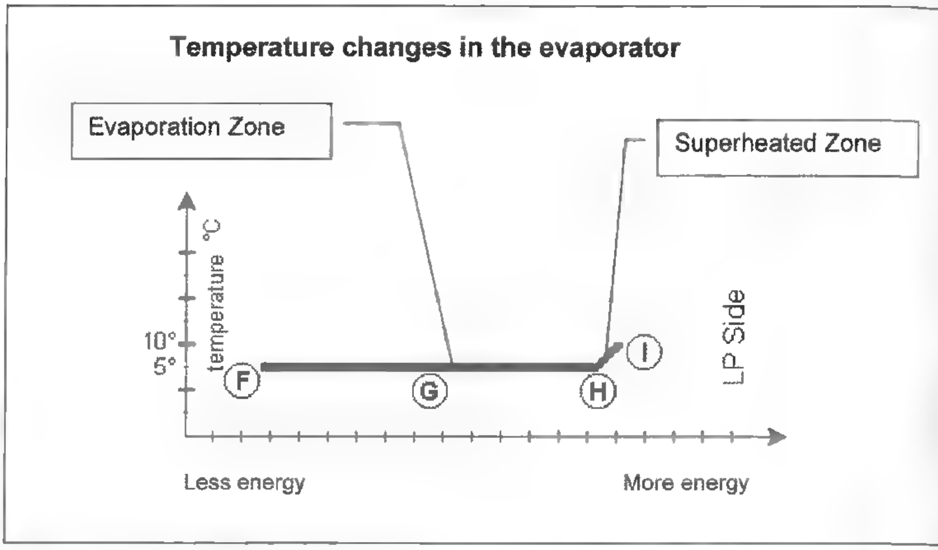
**Point G:** Since point G is situated right in the middle of the evaporator, we can be sure that it is exactly on the evaporation step, and that a thermometer placed at this point would give a reading of (in our example) 5°C, *that is, exactly the same temperature as that indicated by the LP gauge.*

**Point H:** The last droplet of R22 has evaporated, so there is *exactly* 100% vapour at 5°C. Naturally the pressure still remains at 4.8 bar.

**Between H and I:** The refrigerant continues to absorb heat from the air. As it exists as 100% vapour, its temperature progressively increases. We say, then, that it is superheated.

**Point I:** At the evaporator outlet, the pressure is still 4.8 bar, but the temperature of the vapour at the suction side of the compressor is 10°C. We say that it is superheated by 10 – 5 = 5°C, or more usually that **the superheat is 5°C**. The fact that we observe a temperature at I greater than that at the evaporation step allows us to be certain that the compressor is drawing in superheated vapour. If this is the case then there is no risk of the dreaded "liquid hammer", so often fatal to refrigeration systems.

**We can also represent the changes occurring in the R22 in the following way:**




__At point F:__ The refrigerant enters the evaporator as saturated vapour. It has in fact been partially vaporised as it passed through the capillary.

__From F to H:__ Evaporation of the R22 occurs at constant pressure and temperature. Here the evaporation step is at 5°C and 4.8 bar.

__At point H:__ the last droplet of liquid vaporises. This is the end of the evaporation step, and 100% of the refrigerant exists as vapour.

__From H to I:__ the R22 vapour superheats from 5°C to 10°C. We say that the superheat is 10 – 5 = 5°C.

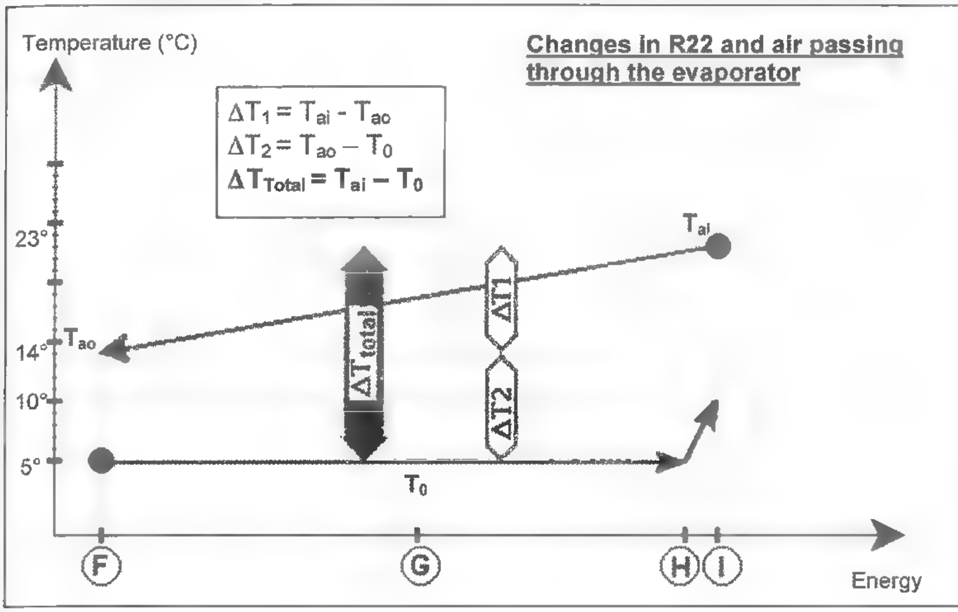
In actual fact, when we measure the LP we can, at the same time, read the temperature of the evaporation step on the gauge.

Exactly, and if you *also* measure the temperature of the refrigerant on the suction side of the compressor, you will immediately know the value of the superheat.

From what follows, you'll see that understanding the superheat value is essential if you want to understand the correct operation of an a/c system.

**Now we'll look at what happens to the air as it passes across the evaporator.**

As the diagram below shows, the air is cooled gradually as the refrigerant evaporates.




We are interested in the following temperatures:

- $T_0$ : Evaporation temperature of the refrigerant.
- $T_{ai}$ : Temperature of the air at the inlet of the evaporator
- $T_{ao}$ : Temperature of the air at the outlet of the evaporator

You'll notice that the refrigerant and the air are in counter- current flow in the evaporator in order to optimise the exchange of heat.

In a 'comfort' a/c system, the temperature differences are generally as follows:

- The temperature difference (ΔT) between the inlet and the outlet is somewhere between 8 and 10°C.

  *In our example, ΔT for the air is 23 – 14 = 9°C.*

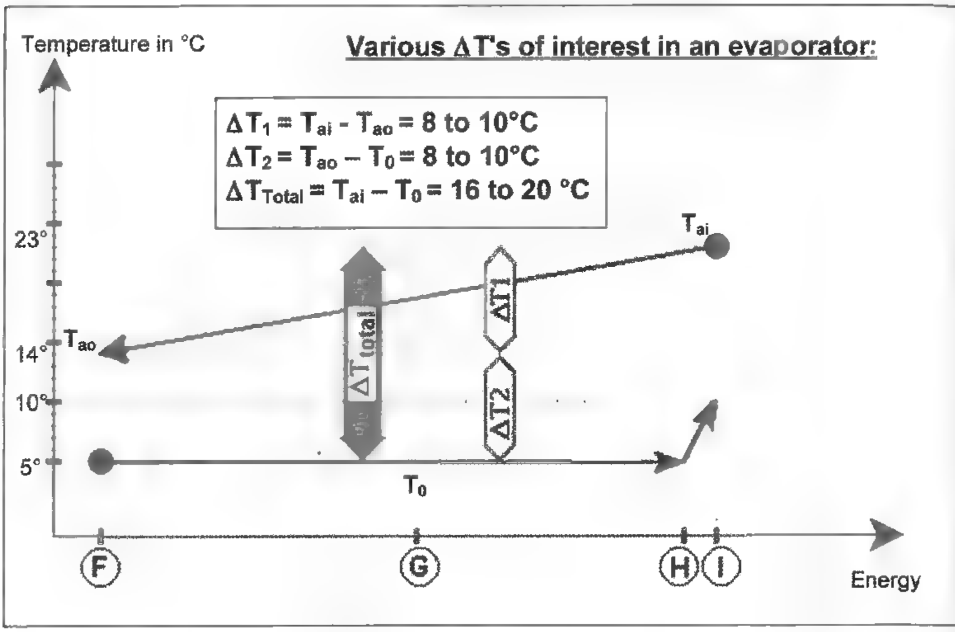
- The temperature difference (ΔT) between the air outlet and the evaporation temperature is also somewhere between 8 and 10°C.

  *In our example, this ΔT is 14 – 5 = 9°C.*

- The temperature difference of most interest to us is that which exists between the evaporation temperature and the air inlet temperature. ***This difference is known as ΔT total for the evaporator.*** It is generally somewhere between 16 and 20°C.
-

*In our example ΔT total is 23 – 5 = 18°C.*

## In Summary:




$\Delta T_{total}$ is the difference between the temperature of the air at the evaporator inlet (that is the ambient temperature of the room being air-conditioned) and the evaporation temperature (read from the LP gauge). The value of this $\Delta T$ is a very useful quantity to know.

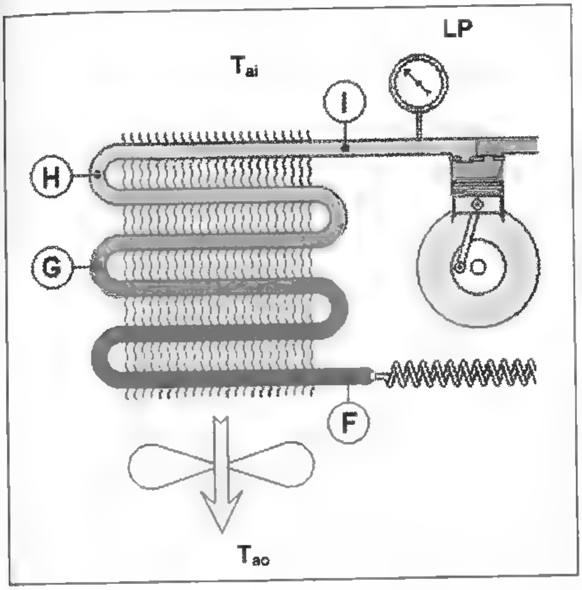
If $\Delta T_{total}$ is of particular interest here, is this for the same reasons as the condenser?


That's exactly right. It's very easy to measure the ambient temperature, so with an average $\Delta T_{total}$ at the evaporator of 18°C, **and knowing that the room temperature is 25°C, the evaporator temperature should be somewhere around 25 – 18 = 7°C!**

So when I connect my LP gauge, the evaporation temperature should be about 7°C. If it's much more or much less than this, I know immediately that something is wrong.

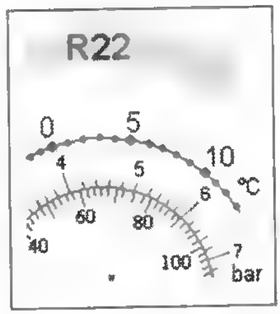
OK, so the LP depends on the temperature of the air at the evaporator inlet, just as the HP depends on the temperature of the air at the condenser inlet. So, altogether, it's not as difficult as all that!

We've just seen the basics of the normal operation of the evaporator. Now we're going to do a little revision exercise.




Ambient temperature: **26°C**
$\Delta T_{total}$ for evaporator:**20°C**
$\Delta T$ of the air: **10°C**
Superheat: **6°C**

To help you, here is the gauge used:




*Now it's over to you. All you have to do is complete the table. Try it for yourself to assess how well you understand this subject before looking at the solutions on the next page...*

| | $T_{ai}$ | $T_{ao}$ | $\Delta T_{total}$ | * $T_0$ | $P_0$ = LP |
|---|---|---|---|---|---|
| Values | **26°C** | | **20°C** | | |

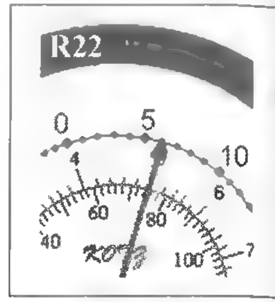
*$T_0$ is the evaporation temperature

| Point | F | G | H | I |
|---|---|---|---|---|
| T in °C | | | | |
| P in bar | | | | |
| * State | | | | |

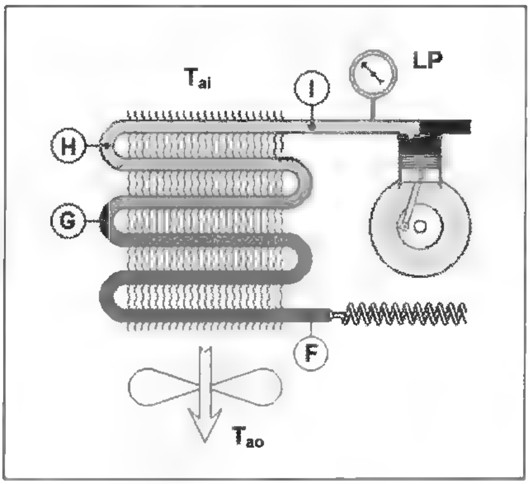
* *State:* enter **V** if the refrigerant exists as superheated **V**apour, **L** if it is as sub-cooled **L**iquid, and **SV** if it is **S**aturated **V**apour.

## Solutions to the exercise:

| | $T_{ai}$ | $T_{ao}$ | $\Delta T_{total}$ | $T_0$ | $P_0$ = LP |
|---|---|---|---|---|---|
| Values | **26°C** | 16°C | **20°C** | 6°C | 5 bar |




- $T_{ao} = T_{ai} - \Delta T$ of the air = 26 -10 = 16°C.
- $T_0 = T_{ai} - \Delta T_{total}$ = 26 - 20 = 6°C.
- LP value: the gauge needle indicates a value of $T_0$ (that is 6°C), and simultaneously a pressure of 5 bar.




- At point **F**, the refrigerant exists as saturated vapour (about 80% liquid and 20% vapour) so the temperature is equal to that of the evaporation step, that is, 6°C.

*The pressure is equal to 5 bar at all points throughout the LP side (including G, H and I).*

- At point **G**, right in the middle of the evaporator, the R22 is still at the evaporation step, that is it exists as saturated vapour at 6°C and 5 bar.
- At point **H**, the refrigerant is at the end of the evaporation step, and the last droplet of liquid has evaporated at 6°C and 5 bar. From point H, therefore, it exists as 100% vapour.
- At point I, the R22 vapour is superheated by 6°C (that is it is 6°C above the temperature of the evaporation step). The temperature of the vapour, therefore, is 6 + 6 = 12°C. As this temperature is greater than the evaporation temperature, we can be sure that the refrigerant is 100% vapour, and that there is no risk to the compressor from "liquid hammer".

| Point | F | G | H | I |
|---|---|---|---|---|
| T in °C | 6°C | 6°C | 6°C | 12°C |
| P in bar | 5 bar | 5 bar | 5 bar | 5 bar |
| State | SV | SV | SV | V |

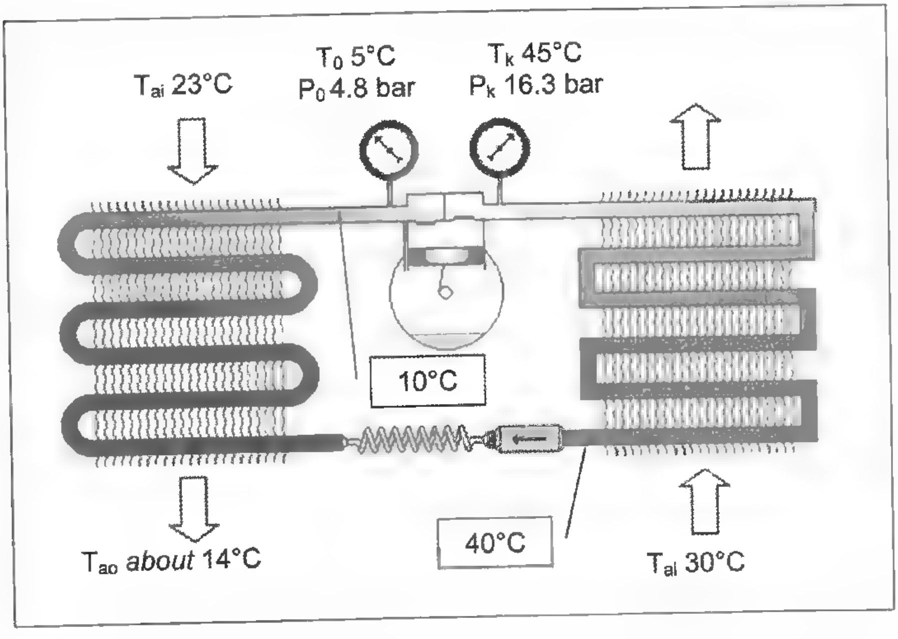
# THE COMPLETE CIRCUIT: NORMAL OPERATION

Now we can round off our studies by listing the normal operating conditions seen in our earlier examples.

Remember these operating conditions:

| **LP Side** (Low pressure) | **HP Side** (High pressure) |
|---|---|
| Temperature of the air at the evaporator inlet: $T_{ai}$ **= 23°C** | Temperature of the air at the condenser inlet: $T_{ai}$ **= 30°C** |
| $\Delta T_{total}$ at the evaporator **= 18°C** (normal value 16 to 20°C) | $\Delta T_{total}$ at the condenser **= 15°C** (normal value 10 to 20°C) |
| Evaporation temperature $T_0 = T_{ai} - \Delta T_{total} = 23 - 18 = \mathbf{5°C}$ | Condensation temperature $T_k = T_{ai} + \Delta T_{total} = 30 + 15 = \mathbf{45°C}$ |
| Low pressure shown on LP gauge: $P_0$ **= 4.8 bar** | High pressure shown on HP gauge: $P_k$ **= 16.3 bar** |
| Superheat **= 5°C** (normal value 5 to 10°C) | Sub-cooling **= 5°C** (normal value 4 to 7°C) |

Which gives on the system:




As we've already seen, the compressor's role is simply to draw in refrigerant from the LP side and discharge it on the HP side...

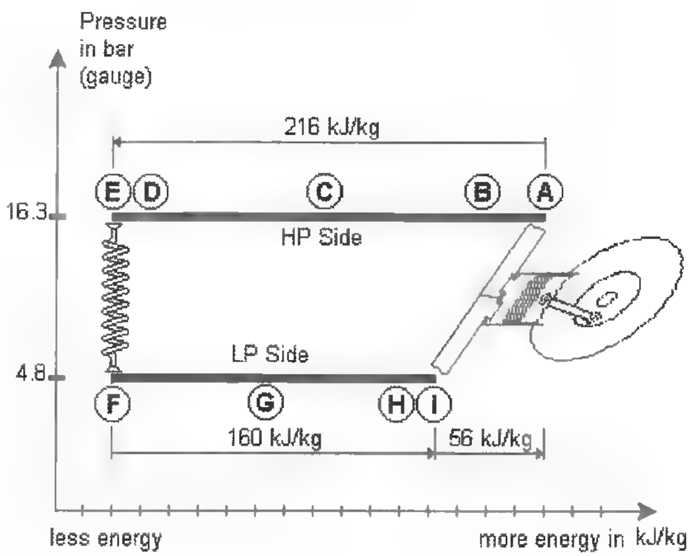
**It is essential that you understand that the compressor doesn't control the LP and HP pressures. *These pressures depend only on the $\Delta T_{total}$* of the evaporator (for the LP) the $\Delta T_{total}$ of the condenser (for the HP) *and the temperature of the air at the inlet of each of these heat exchangers.***

During the 80's piston compressors were the commonest design used in comfort A/C. Since then, because of noise levels, and for performance and reliability reasons, other types, such as rotary and especially scroll compressors, have become predominant.

However, whatever the technology involved, the result is still the same: **HP and LP pressures are always a result of the system's operating conditions.**

We can represent these operating conditions as shown in the diagram below:

**PRESSURE CHANGES IN A REFRIGERATION CIRCUIT**




You'll observe that LP is 4.8 bar and that HP is 16.3 bar.

The points A to E correspond to those used in our study of condensers (see page 130). The points F to I have been used for the evaporator (see page 153).

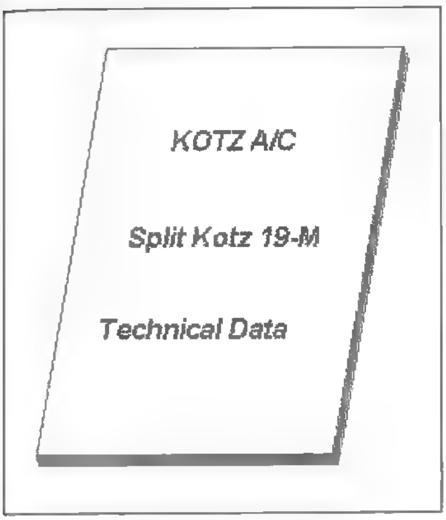
*Note that we've shown the quantities of energy involved per kg of refrigerant in the system.*

# TECHNICAL DATA: GENERAL POINTS

Whatever model of air conditioning unit is involved, the technical data supplied with it is very often a mine of important information for those who can read it.

Unfortunately, this data isn't always all that easy to decipher, especially for the inexperienced, which is why we'll now read through it together. Following the instructions supplied by the manufacturer is by far the best way of guaranteeing trouble- free operation, and so of satisfying your customer. This, of course, *is the best for you too*.

We would expect to find the following data supplied:

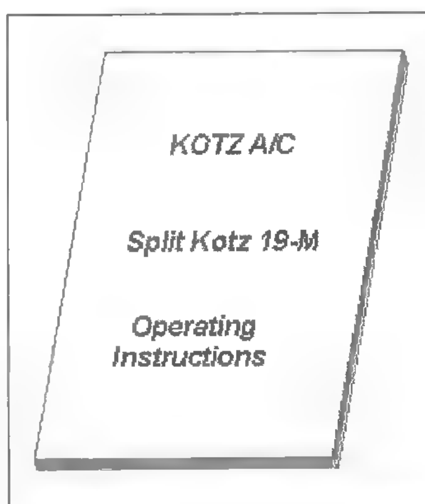



- General information.
- Physical and electrical details for the equipment.
- Operating conditions and allowable limits.
- Recommendations for selecting the location of the equipment's external and internal units.
- Details for refrigeration connections.
- Details of the electrical supply and connections.
- The remote control and display panel.
- The normal operation of the equipment involved.
- Testing and commissioning.
- Maintenance of the equipment.

Take care not to confuse the technical data with the operating instructions provided for the client's use.

The operating instructions explain to the user in a simple and understandable manner how to get the best out of his equipment, and how to perform minor preventative maintenance tasks.

The two sets of documents have different roles, and differ considerably in their level of detail. Generally, the details given in the operating instructions also appear in the technical data.



In the following chapters we'll examine the page that is shown below from a Technical Data document in some detail:

| | Feature | Kotz 2.0-MA | Kotz 12-PA |
|---|---|---|---|
| General | Cooling Capacity | 2000 Watts | 12000 Watts |
| | Heating Capacity | - | 14000 Watts |
| | Dehumidification rate | ca. 1 l/h | ca. 6 l/h |
| | Power Supply | 220V/1~/50Hz | 380V/3~/50Hz |
| | Supply connection: | internal unit | external unit |
| | Current | 2.8 A | 8.4 A |
| | Power consumed | 615 Watts | 4600 Watts |
| | C.O.P | - | 3.0 |
| | Expansion device | capillary | capillary |
| | Condenser type | air- cooled | air- cooled |
| Internal Unit | Reference No. | Kotz 2.0-MI | Kotz 12-PI |
| | Colour | Ivory | Ivory |
| | Dimensions (H x W x D) | 360x800x1200 mm | 240x1500x650 mm |
| | Weight | 9 kg | 44 kg |
| | V / I / P | 220V/0.17A/35W | 220V/0.28A/55W x 2 |
| | Control | Infra red remote | remote cable |
| | Noise level | 36 dBA | 57 dBA |
| | Fan type | tangential x 1 | centrifugal x 4 |
| | Air flow LV | 3.6 m$^3$/min | 20 m$^3$/min |
| | MV | 4.7 m$^3$/min | 24 m$^3$/min |
| | HV | 5.7 m$^3$/min | 28 m$^3$/min |
| | Air Filter | removable, washable | removable, washable |
| External Unit | Reference No. | Kotz 2.0-EA | Kotz 12-EA |
| | Colour | natural | natural |
| | Dimensions (H x W x D) | 550x750x250 mm | 1250x900x350 mm |
| | Weight | 30 kg | 120 kg |
| | Noise level | 55 dBA | 60 dBA |
| | Fan type | Axial x 1 | Axial x 2 |
| | Air flow | 23 m$^3$/min | 88 m$^3$/min |
| | V / I / P | 220V/0,13A/25W | 220V/0,3A/60W x 2 |
| | Compressor type | Rotary hermetic x 1 | Piston hermetic x 1 |
| | V / I / P | 220V/2.5A/550W | 380V/65A/3,75kW |
| | I at start up | 18 A | 49 A |
| | Refrigerant | R22 | R22 |
| | Charge | 0.72 kg | 2.8 kg |
| | Lubricant | RV-Mineral | RV-Ester |
| | volume | 0.4 litre | 1.75 litre |
| Connections | Liquid pipework | 1/4" | 3/8" |
| | Gas pipework | 3/8" | 3/4" |
| | Connector type | Quick | Flare |
| | Maximum pipe length | 10 m | 25 m |
| | Max. Ht. difference If: | | |
| | Ext unit higher | 5 m | 20 m |
| | Ext unit lower | 5 m | 15 m |
| | Pipework insulation | Gas and Liquid | Gas and Liquid |
| | Condensate Removal | ∅ 16 mm | ∅ 24 mm |
| | Supply cable | 3G2.5 | 5G2.5 |
| | Control cable | 3G1.5 | 8G1.5 |

# TECHNICAL DATA: POWER & CAPACITY

We'll start by looking at the power and capacity values shown in bold type in the table underneath; that is the refrigerating capacity, heating capacity, dehumidification rate, power consumed, and C.O.P.

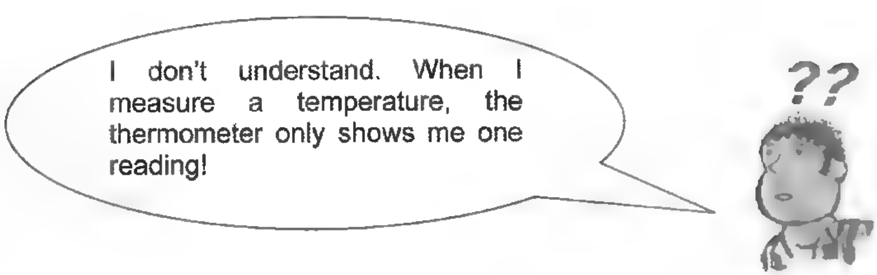
| | Feature | Kotz 2.0-MA | Kotz 12-PA |
|---|---|---|---|
| General | **Cooling capacity** | **2000 Watts** | **12000 Watts** |
| | **Heating capacity** | **-** | **14000 Watts** |
| | **Dehumidification** | **ca. 1 l/h** | **ca. 6 l/h** |
| | Supply | 220V/1~/50Hz | 380V/3~/50Hz |
| | Power supply to: | internal unit | external unit |
| | Current | 2.8 A | 8.4 A |
| | **Power consumed** | **615 Watts** | **4600 Watts** |
| | **C.O.P** | **-** | **3.0** |
| | Expansion device | capillary | capillary |
| | Condenser type | air- cooled | air- cooled |

## Dry and Wet Temperature:

The data provided by a manufacturer always refers to specific operating conditions. These conditions are standardised to allow performance comparisons between equipment from different manufacturers. For example, the international standard ISO R 859 – NF E 36101 specifies the following conditions:

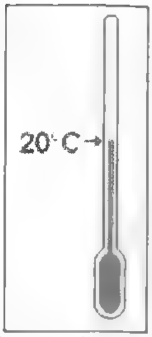
| Temperatures / Settings | Interior Conditions | | Exterior Conditions | |
|---|---|---|---|---|
| | Dry Bulb | Wet Bulb | Dry Bulb | Wet Bulb |
| COLD | 27°C | 19°C | 35°C | 24°C |
| HOT | 20°C | - | 7°C | 6°C |
| Standard | ISO R 859 – NF E 36101 | | | |

You'll notice that there are two types of temperature: Dry bulb temperatures, and wet bulb temperatures.



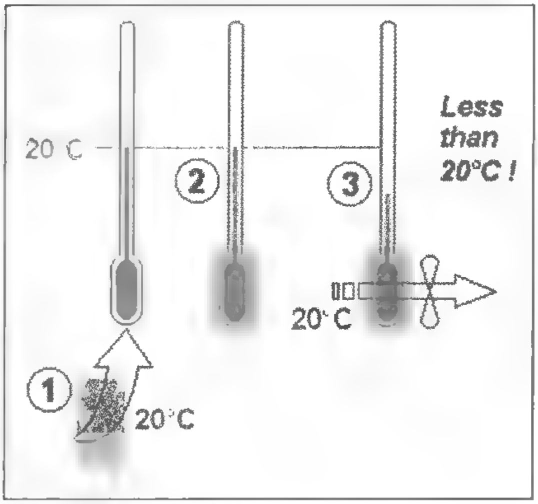

*Have you got an explanation of this for Charlie?*

We're used to using an ordinary thermometer (mercury or alcohol) which shows us the ambient temperature (e.g. 20°C) of its surroundings.




This type of thermometer is called a "dry" thermometer. There is no trace of water or moisture on the bulb. Therefore the temperature it shows us is called the "dry bulb temperature" or perhaps the "dry temperature".

However, as we saw on page 62, the air that surrounds us contains water vapour. We know that this vapour condenses on the cold surfaces of the evaporator to form the condensates. We'll examine this subject again, and in more detail, later on, but at this point we need to appreciate that the quantities of water vapour contained in air could be of importance.

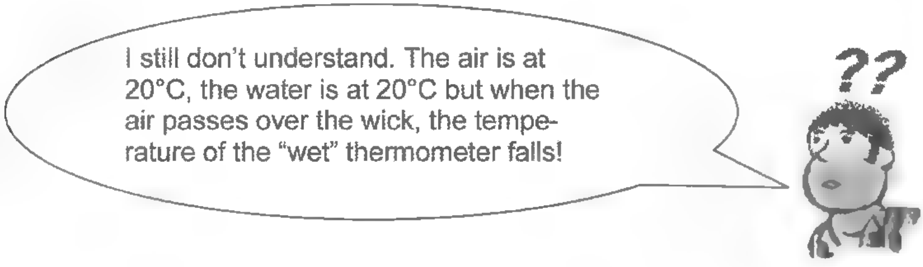



Let's examine the experiment shown opposite. The dry thermometer reads 20°C. We moisten a small piece of wick with water, also at 20°C (figure 1), and wrap it around the bulb.

Since the water is at 20°C, the thermometer still reads 20°C (figure 2).

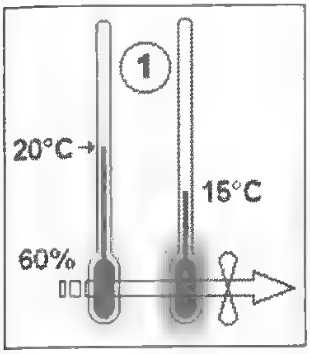
*Now, if we circulate the air in the room at 20°C over the wet wick we observe that the thermometer's temperature reading falls!*

This temperature obtained with the wet wick is known as the "wet temperature" or "wet bulb temperature". (There are mechanical instruments available, fitted with two thermometers and a small fan, which have been specifically designed to perform this measurement. They are known as hygrometers).




*Do you have any ideas about what's happening?*

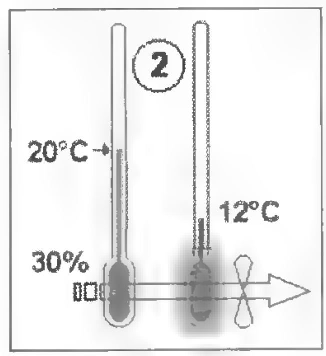
We know that heat always flows from a hotter body to a colder one. This is the same in all areas of physics; the "richer" body always gives up a property to the "poorer" one. This applies to moisture in exactly the same way. Moisture passes from wetter materials to dryer ones. This is why air always tries to absorb moisture. *The wick in our experiment is saturated with water, so…*




In 1, the air at 20°C contains 60% humidity (that is, it contains only 60% of the maximum possible amount, so it could take up more).

As it passes over the wick soaked with water, the air absorbs moisture and emerges from the small fan wetter than it was on entry. *But air is a gas, and gases are quite unable to absorb liquids which are a lot denser than they are!*

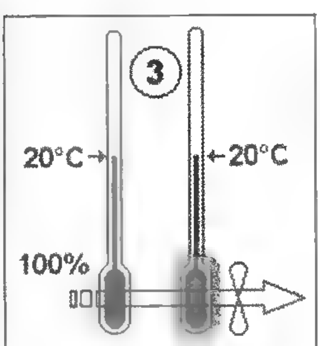
***So it has to be water <u>vapour</u> that is absorbed as the air passes over the wick.*** However in order for the transformation of liquid water into water vapour to occur, heat is required (this is an evaporation step). *This is why the wick, its water, and then the thermometer get colder!* In this instance, the wet bulb gives a reading of 15°C.




In the situation shown in 2, the air at 20°C contains only 30% humidity, that is, it is capable of taking up even more water than in the above example.

As it passes over the wick saturated with water, the air therefore absorbs more moisture than in the previous case. But for more water vapour to be absorbed, more liquid water has to evaporate.

The wick, its water and the thermometer must therefore release more heat to vaporise the water, and so the fall in their temperature is greater. In this instance, the wet bulb gives a reading of 12°C.



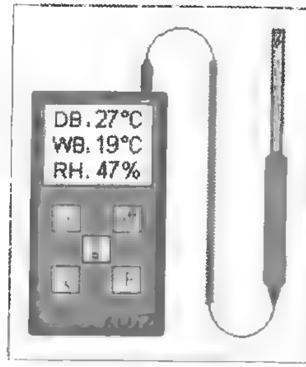

In this last example (3) the air at 20°C contains 100% humidity, that is, it is completely saturated, and it can absorb no more water whatsoever.

As it passes over the wet wick, the air is incapable of absorbing any more moisture.

There is therefore no evaporation of the water on the wick, and both thermometers give the same temperature reading of 20°C.

You should remember that the wet temperature is always less than or equal to the dry temperature.

So we can say that the smaller the difference (or 'depression') between the dry temperature and the wet temperature, then the wetter the air is. If the dry and wet temperatures are identical, the air is said to be saturated. At this particular point, the air can absorb no more water. It is at 100% of its absorption capacity, or it is said to be at 100% **R**elative **H**umidity (**RH**). If the quantity of water in the air equals half its maximum capacity, its relative humidity is likewise said to have a value of 50%.




Nowadays, digital electronic thermometers are the commonest types in use. If you have one with a "hygrometer" function, it shows you the dry temperature, the wet temperature, and the relative humidity.

*Take care, as the probe of these electronic hygrometers should never be allowed to become wet, otherwise the instrument may be seriously damaged.*


How would you measure the dry and wet temperature using a mechanical hygrometer then?

Manufacturers supply a useful little scale with the instrument. All you do is mark off both the temperatures measured, and so directly read off the relative humidity of the room.

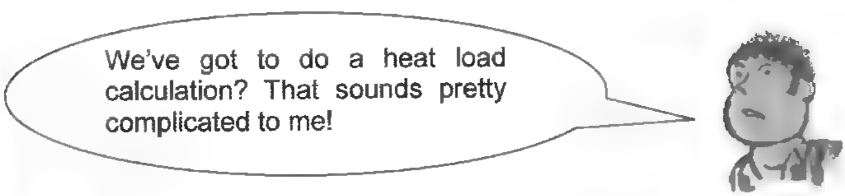

OK. I understand that, but I've got another question. The air surrounding us contains water vapour, which is a gas, but why is this is so important with regards for the capacity of our air conditioning unit?

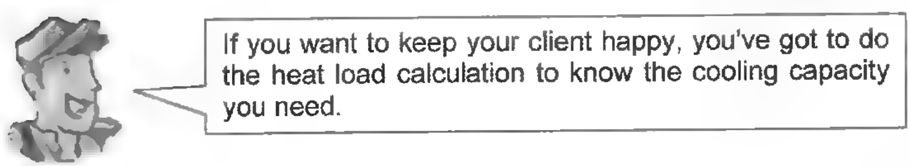
## Cooling Capacity:

If we start by looking at the **Kotz 2.0-MA** model, for example, then according to the technical data the cooling capacity of this unit is 2000 Watts. This cooling capacity (sometimes called 'cooling power' or 'refrigerating power' or 'refrigerating capacity') corresponds to the amount of heat that the evaporator is capable of absorbing.

If we install this equipment in a room where the sum of the heat sources is 2000 W, it will be able to absorb this and maintain the required temperature. On the other hand, if the heat sources are greater than 2000 W, the ambient temperature will increase, and the client will certainly not be happy. So before installing an air conditioning system, we must know the amount of heat that it will need to absorb from the room.

When we need to choose an air conditioning system, we must perform what is known as a heat load calculation for the area in order to know the value of the external thermal load (wall, ceiling, windows etc.) and of the internal load (occupants, lighting, machines etc.) The sum of all these sources allows us to specify the cooling capacity of the air conditioning unit we are to install.



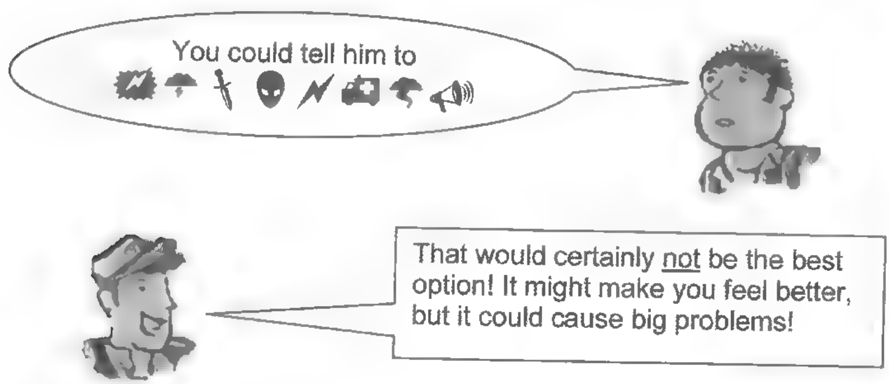

But don't panic! Your supplier can provide you with simplified methods for thermal load calculations in the form of tables, numerical scales or even computer software.

Be warned, though. For comfort air conditioning, there are a set of ratios which say that for a ceiling height of 2.5 m, the cooling capacity needed in an installation is somewhere between 80 and 120 Watts per m² of floor space. These ratios only provide you with an ***order of magnitude figure*** for the capacity you need. Just remember that if a dispute gets to litigation, the installer should be in a position to justify his choice of equipment!

You'd be well advised to perform a heat load calculation for every installation, stipulating precisely the internal and external loads, as well as the frequency with which doors are opened, especially those giving on to the exterior.

Imagine that a retailer asks you to air- condition his store. After receiving his instructions, you perform the heat load calculation of the location, but with the doors giving onto the pedestrianised area permanently closed. He accepts your quotation, you complete the installation, and you commission the system. The client is happy and for the time being all is well. Two weeks later, your client complains that it is too warm in his store. When you arrive, you find the doors wide open.

As you didn't have him sign an accurate heat load calculation with your quotation, your client now tells you that there was never a question of leaving the door closed. He says that this would make it too difficult for his customers to enter the store. At this point, what can you do? What courses of action are open to you?




We've taken the example of an open door, but the same problems could arise if lighting, machines, personnel etc. are increased, say. So always cover yourself and do a heat load calculation (even a simplified one), include it in your quotation and get it signed. Clients don't always like to pay their bills on time, nor do they always act in good faith.

Let's get back to our equipment. You've performed the heat load calculation, and you come up with a required cooling capacity for the installation of 1920W. Therefore you'd be interested in the **Kotz 2.0-MA** model, with its 2000 W capacity, which would seem to meet your requirements exactly.

Note that this capacity refers to the amount of heat that the evaporator is capable of absorbing from the air under the operating conditions specified in the Standard:

| Temperatures / Settings | **Internal Conditions** | | **External Conditions** | |
|---|---|---|---|---|
| | Dry Bulb | Wet Bulb | Dry Bulb | Wet Bulb |
| **COLD** | **27°C** | **19°C** | **35°C** | **24°C** |
| WARM | 20°C | - | 7°C | 6°C |
| Standard | ISO R 859 – NF E 36101 | | | |

This indicates that with an external temperature of 35°C, the internal temperature should be about 27°C.


Well, a 'comfort' air conditioning system provides comfort. It does not actually 'condition' the air. We don't maintain a strictly constant temperature in a room, but rather we maintain a pleasant temperature.

In comfort air conditioning, with "summer" cooling loads, the equipment is designed to provide a maximum temperature difference of 7 to 8°C between room ambient and external temperatures. In fact, a temperature difference of more than 8°C can become unpleasant, and can even damage your health.

In summer, our body becomes hot, and perspires. This is why we dress lightly, often with bare arms. If it's 30°C outside, and we enter a room at 20°C, say, then our body is subjected to a "cold shock". We might shiver, catch a cold, or other infections, suffer muscular problems etc. Where is the "comfort" if this happens?

At sometime, you must certainly have heard remarks of the following sort: " *air- conditioning? Oh no! You'll catch pneumonia with that sort of contraption".* This won't be the case with your installations as long as you know how to select and install them correctly. You should also remember that your role includes explaining to your clients how to use their air conditioning systems.

***Always bear in mind that a satisfied customer is a good advertisement. An unhappy one will lose clients for you.***

## Dehumidification rate:

In the data on p162, the manufacturer quotes a dehumidification rate of about one litre an hour for the model **Kotz 2.0-MA** (under the nominal conditions of ISO R 859 – NF E 36101).

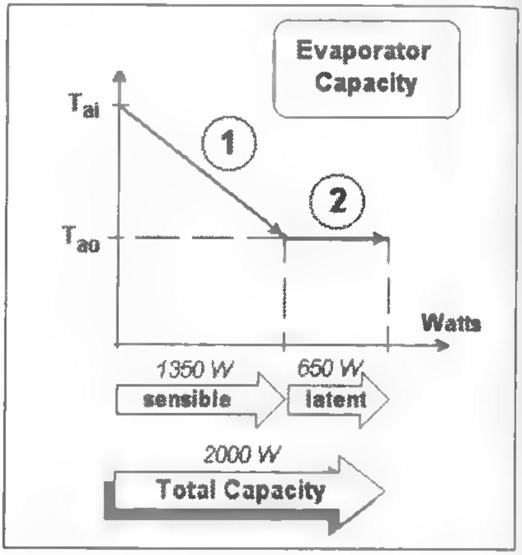
| | Features | Kotz 2.0-MA | Kotz 12-PA |
|---|---|---|---|
| General | **Cooling capacity** | **2000 Watts** | **12000 Watts** |
| | **Heating capacity** | **-** | **14000 Watts** |
| | **Dehumidification** | **ca. 1 l/h** | **ca. 6 l/h** |
| | **Power consumed** | **615 Watts** | **4600 Watts** |
| | **C.O.P** | **-** | **3.0** |

As we saw on p62, water is produced from the condensation of water vapour contained in air on a cold surface...

But for the water vapour (a gas) contained in the air to be transformed into condensate (a liquid), there must be heat removed from the water vapour (there is, therefore, a condensation step taking place). Then the condensates will be drained away.

**This means that part of the evaporator's capacity is used to condense water vapour, which is then poured down the drain!**

This capacity that is sent down the drain is far from negligible, since in our example it represents about 650 Watts. As the total capacity of the evaporator is 2000 Watts, this means that only 1350 Watts are used to cool the air.



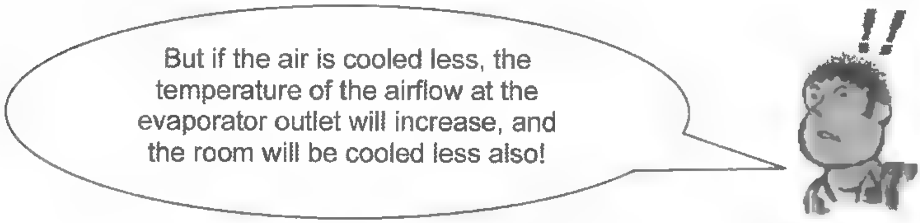

So the refrigerating capacity of 2000 watts quoted by the manufacturer refers to the total capacity of the A/C system.

This total capacity (2000 Watts) is the sum of:

1. *the sensible capacity,* (1350 Watts) which can be used to lower the air temperature.
2. *the latent capacity* (650 Watts) which is used up in transforming part of the water vapour contained in the air into condensates (at a rate of 1 litre per hour), which are then removed.

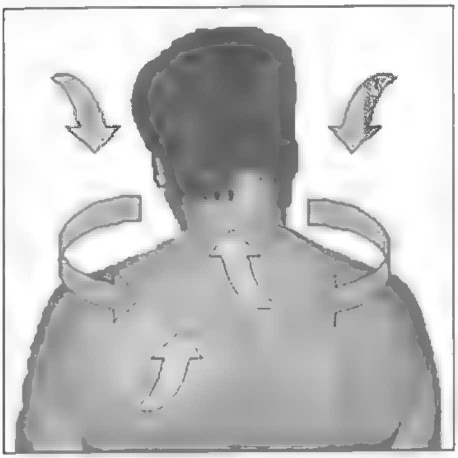
So, for a given A/C unit, the larger the latent capacity used, the smaller is the amount of sensible capacity available.

You could also say that the more moisture that is contained in the ambient air, the more condensation there would be. This means that the more latent capacity that is consumed, the less sensible capacity would be available (in our example, only 1350 W are available to cool the room being air-conditioned). If the sensible capacity is reduced, the air will be cooled less as it passes over the evaporator.




*Do you agree with Charlie?*

Charlie isn't wrong, but he's not aware of another effect.



In summer, we have a thin layer of perspiration over the whole surface of our body, *which increases as it gets warmer*, and which is principally made up of water.

On all the exposed parts of the body (the face, neck, arms etc.), this thin layer of liquid water is in direct contact with the "dry" air that surrounds it.

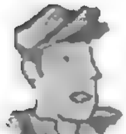
It produces the same sort of effect as we've studied with the hygrometer. The air takes up perspiration from the body surface. This change from a liquid state to the vapour state requires heat. This heat is taken from the body, and a sensation of coolness is produced.

In this way, the dryer the air is, the more perspiration it absorbs to make us cool. *This is why warm, dry air gives our brain the same sensations of 'comfort' as cold, moist air.*

In, fact, some air conditioning equipment features a dehumidification ("DRY") function, that enable us to reduce the ambient humidity without lowering the temperature. The drier air leaves us with the impression of pleasant and comfortable surroundings.

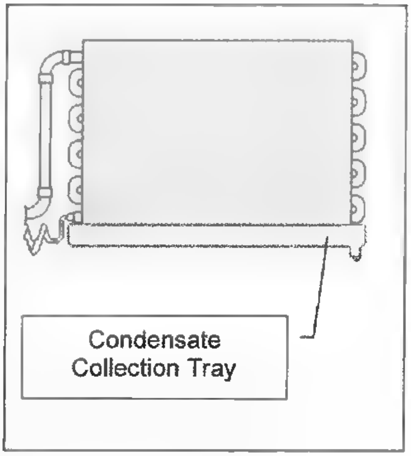
OK, I think that I understand this. Just as our bodies are sensitive to temperature, they are also affected by humidity. I mustn't only consider temperature, then.

But if water vapor being removed at the evaporator helps us, what do we do about the condensates ?



You're quite right to have remembered about the condensates. <u>Never ignore condensates</u>, as they can cause serious problems.

Indeed, we should never forget about the condensed water that collects in the tray found beneath the evaporator.



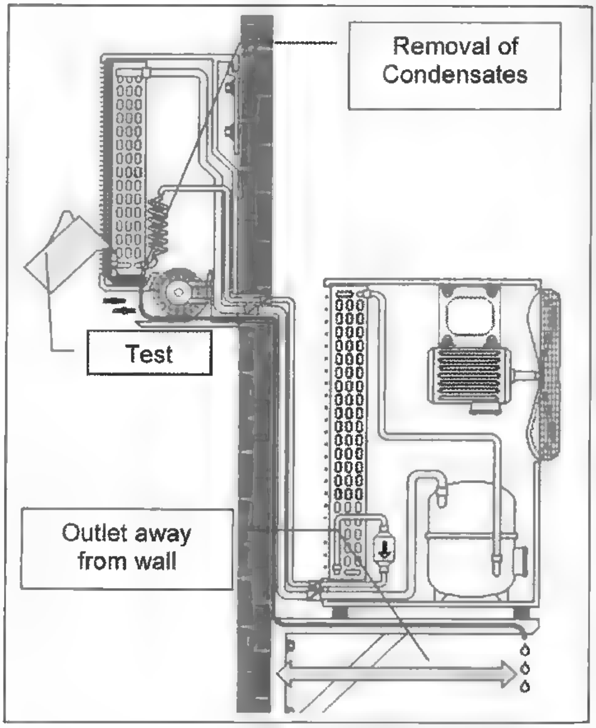

A litre per hour for a small, 2000W, air conditioning system may not seem a lot, but after, say, ten hours in operation, this adds up to 10 litres of water. This sort of volume is certainly more than enough to cause a small flood. The result of this could be soaked carpets, or even damage to the attractively decorated ceiling of your neighbour below etc.

To avoid these problems, never connect the condensate drain so that it flows...

- *Into potted plants.* They'll quickly overflow, and as the condensed water contains very few minerals, you could actually "finish off" your plants for good.
- *Into a bucket.* This could really prove to be a chore for the user, and sooner or later the bucket will inevitably overflow!
- *Onto a pavement.* It will make it permanently wet, and if it happens to fall onto a passer by, you could well be the one held responsible!
- *Onto a balcony.* It will run into the property of your neighbour below.
- *Directly onto an outside wall.* At best, the result will be an unpleasant stain, and at worst the water could penetrate right through the wall.

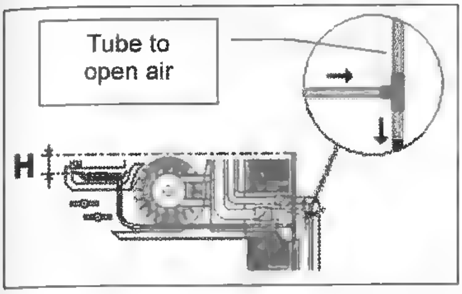
Effectively, there are only two practical options left open to you. These are either making a connection into a rain- water pipe, or into the waste- water system. *With the last option it is vital that you fit a U-bend to avoid the possibility of producing unpleasant odours!*

However, if connecting the condensate outlet to a suitable drain is impossible, you could release them outside, away from a wall, as shown in the diagram opposite. Always make sure that the water doesn't affect neighbours; it's much easier to plan these things beforehand than to be forced to move everything later!



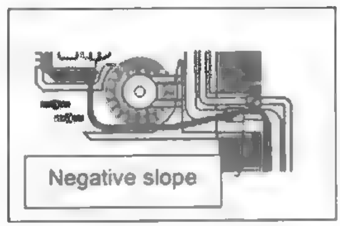
Always test the effectiveness of the condensate drainage system by pouring some water into the tray, and ensuring that it drains away properly.

*Note that* the slight reduction in pressure produced above the condensate tray by the fan could hamper the free drainage of the water produced. This is especially the case where the drainage pipework is long and tortuous. So even if drainage works properly with the fan at rest, there could be an overflow when the fan is in operation. It's much better not to take this risk, and to test the drainage when the fan is running.




If the problem persists, a little trick might provide a solution. All that is needed is a t-piece on the outlet pipework as shown opposite. The pipe that is open to the air must be cut off a few centimetres (**H**) above the highest level of water in the tray. This is done to prevent the water in the tray from actually flowing out *via* this tube.

The condensed water is removed by gravity. Therefore it is essential to maintain a gradual slope towards the outlet, and above all never to allow a negative slope. Always follow the manu-facturer's recommendations on this to the letter.




***The problems associated with removal of condensates must be fully examined when choosing the location of the internal unit:***

## Heating capacity:

To continue our examination of the Technical Data, let's look at the model **Kotz 12-PA**, with a heating capacity of 14 000 W.

| | Feature | Kotz 2.0-MA | Kotz 12-PA |
|---|---|---|---|
| General | **Cooling Capacity** | **2000 Watts** | **12000 Watts** |
| | **Heating Capacity** | **-** | **14000 Watts** |
| | **Dehumidification Rate** | **ca. 1 l/h** | **ca. 6 l/h** |
| | **Power consumed** | **615 Watts** | **4600 Watts** |
| | C.O.P | - | **3.0** |

In order to provide a source of heating in winter, or out of season, some units are supplied fitted with electric heating elements, but many systems use a different technology, and are "reversible" air conditioning systems.

In this latter case, the refrigeration cycle is reversed. Here, the evaporator absorbs heat from the external air and the condenser discharges it into the room to be heated. A small 4-way refrigeration valve performs this reversal. We'll examine this device in more detail on page 246.

## Power consumed:

As indicated in the table below, the model **Kotz 12-PA** consumes electrical power at a rate of 4 600 Watts.

| | Feature | Kotz 2.0-MA | Kotz 12-PA |
|---|---|---|---|
| General | **Cooling Capacity** | **2000 Watts** | **12000 Watts** |
| | **Heating Capacity** | **-** | **14000 Watts** |
| | **Dehumidification rate** | **ca. 1 l/h** | **ca. 6 l/h** |
| | **Power consumed** | **615 Watts** | **4600 Watts** |
| | **C.O.P** | **-** | **3.0** |

The electrical power consumed by a unit refers, as its name indicates, to the total electrical power it uses. This is the electrical energy that must be purchased from an electricity supplier.

The calorific capacity available for heating from this unit is 14000 W, whereas it consumes only 4600 W. So the heating effect isn't produced by electrical heating elements, as the equipment would then also consume 14000 W.

For reversible air conditioning units, we refer to the **C**oefficient of **O**ptimal **P**erformance (C.O.P) when it operates in the heating mode. This coefficient of performance is the ratio of the heating capacity produced by the condenser (which is used to heat the room) and the power consumed by the compressor. In our example the COP is = 3.04. This means that for every kW purchased from the Electricity Company, we get a heating capacity at the condenser of 3.04 kW. This sounds very interesting, doesn't it?

Remember that performances are quoted for the nominal conditions of the international standard ISO R 859 – NF E 36101:

| Temperatures / Settings | Internal Conditions | | External Conditions | |
|---|---|---|---|---|
| | Dry Bulb | Wet Bulb | Dry Bulb | Wet Bulb |
| COLD | 27°C | 19°C | 35°C | 24°C |
| **HOT** | **20°C** | **-** | **7°C** | **6°C** |
| Standard | ISO R 859 – NF E 36101 | | | |

In our example, with an external dry temperature of 7°C and an external wet temperature of 6°C, the COP will be 3.04.

So, a reversible air conditioning system can cool us in the summer (by absorbing the heat in a room and discharging it outside), and provide heat in the winter (by absorbing heat from outside and discharging it inside a room). We should already be able to see that the colder it is outside, the smaller the amount of heat absorbed by the evaporator and the smaller the value of COP.

However, the reversible air conditioning system could be an economic proposition for spring and autumn operation, and is entirely justifiable in regions where winter is fairly mild.

# TECHNICAL DATA: THE INTERNAL UNIT

Let's continue our examination of the data on page 162 by looking at the characteristics of the internal unit:

| | Feature | Kotz 2.0-MA | Kotz 12-PA |
|---|---|---|---|
| Internal Unit | Reference No. | Kotz 20-MI | Kotz 12-PI |
| | Colour | Ivory | Ivory |
| | Dimensions (H x W x D) | 360x800x1200 mm | 240x1500x650 mm |
| | Weight | 9 kg | 44 kg |
| | V / I / P | 220V/0,17A/35W | 220V/0,28A/55W x2 |
| | Control | infra red remote | remote cable |
| | Noise Level | 36 dBA | 57 dBA |
| | Fan type | tangential x1 | centrifugal x4 |
| | Airflow LV | 3.6 $m^3$/min | 20 $m^3$/min |
| | MV | 4.7 $m^3$/min | 24 $m^3$/min |
| | HV | 5.7 $m^3$/min | 28 $m^3$/min |
| | Air Filter | Removable, washable | Removable, washable |

## Reference Nos. and Types of Unit:

In some ways, the reference numbers are identity cards for the equipment. They allow you to correctly order any replacement parts that may be needed. They should be carefully read and noted. They are often important sources of information that enable you to quickly identify the unit's characteristics. Unfortunately, just to make the installer's life more difficult, each manufacturer uses different schemes for model numbers.

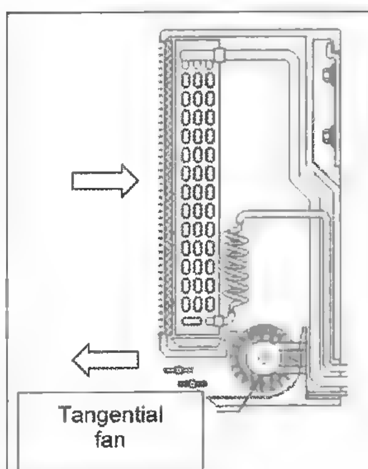
In our table, there are two reference numbers for the internal units:

- **Kotz 2.0-MI** : **Kotz** identifies the manufacturer; **2.0** refers to the cooling capacity (2 kW); **MI** is the manufacturer's code for a wall mounted unit.
- **Kotz 12-PI**: **Kotz** again identifies the manufacturer; **12** refers to the cooling capacity (12 kW); **PI** is the manufacturer's code for a ceiling mounted interior unit.

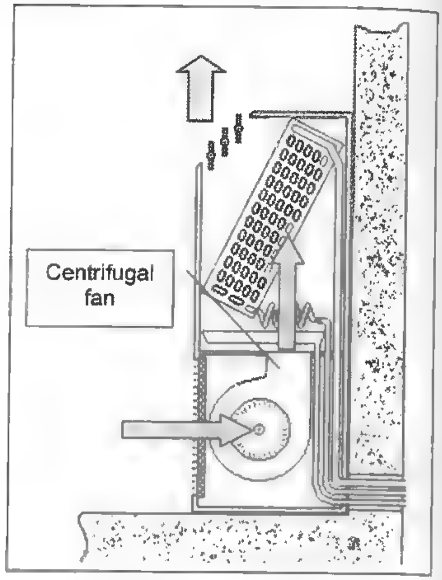
## Wall Mounted Units:

Wall mounted split system units are the most common type in use. Their capacity range is from about 1000 W to 7000 W and they are available as "cooling only" or " reversible ".

Wall mounted interior units are equipped with tangential fans which have the advantage of being particularly quiet. They are located high on a wall, so there will be good distribution of air in the room, and this helps removal of condensates by gravity. These three major advantages explain the success of the wall-mounted split system.



## Console Units:




The range of " console " split systems available is smaller than that of wall mounted systems. Models range from about 2500 W to 6000 Watts, as "reversible" and "cooling only" types.

The internal unit (the console) is located at floor level and is fixed to a wall. This design is often fitted with a centrifugal fan.

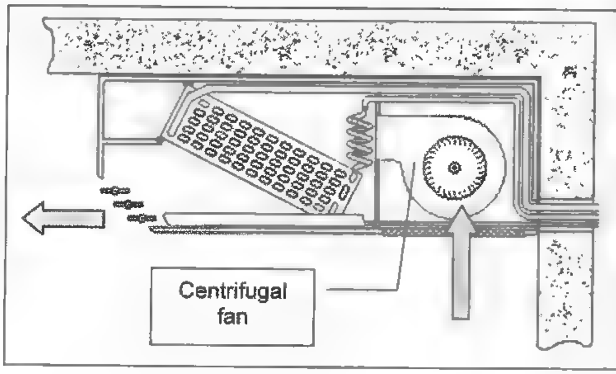
A centrifugal fan resembles a snail's shell, and air is continually drawn in through the centre of the fan, as indicated opposite.

This type of unit is frequently used in offices, and located beneath a window, especially where the presence of cabinets or shelves prevents the installation of a wall mounted split system.

## Ceiling Mounted Units:

There are three types of ceiling mounted units: exposed units, flush fitting (recessed) units and ducted units.

### Exposed units:




The exposed air conditioning unit resembles a console unit, except that it's fitted horizontally to a ceiling.

Particular care is needed in installation of this type of unit, especially regarding the removal of condensates; otherwise you might find that it's raining in the room being air-conditioned!

### The recessed ceiling mounted unit:

Recessed ceiling units are designed to be installed in a false ceiling, with only air outlet and intake grills being visible. They are aesthetically more acceptable than exposed units, but require a false ceiling with a gap of up to 30, or even 35 cm.

This type of equipment is often fitted with a condensate removal pump (which ensures the easy removal and disposal of condensates).

Note that this pump may cause an unexpected failure in an A/C system. To prevent overflow of the condensate tray, a level switch can be fitted to stop the system if there is a problem with this pump. So when, despite your best efforts, such a system stubbornly refuses to run, check the operation of this switch!

These units are available in capacities ranging from about 5 to 12 kW, with "cooling only" or "reversible" options.

**Ducted ceiling mounted systems:**

Ducted ceiling mounted systems have all their equipment recessed into a false ceiling. This system has a series of ducts to carry air drawn into the unit, and to discharge cooled air out into the air- conditioned areas.

The capacity of these split systems starts at about 5 kW and can reach several dozen kW. In these systems, charging of refrigerant often has to be performed by the installation engineer.

Also, if we wish to obtain the correct airflow in an area, the ventilation must be controlled and networked so that it corresponds to the characteristics of the ducting.

We have to design and install the ductwork, calculate the refrigerant charge, calculate the airflow...
I get the impression that this is becoming a bit too complicated for me...

In reality, to install this type of system, you need the correct equipment and training. With these systems we're approaching the realms of "true air-conditioning" or "precision air conditioning", and moving away from our objective, which is to become competent in "comfort" A/C.

In effect, with these types of systems we're starting to get involved with whole new categories of equipment.

Nevertheless, we should note that the operation of the refrigeration circuit is identical. This is why the repair techniques that we'll be seeing very soon will be valid whatever type of split system is installed.

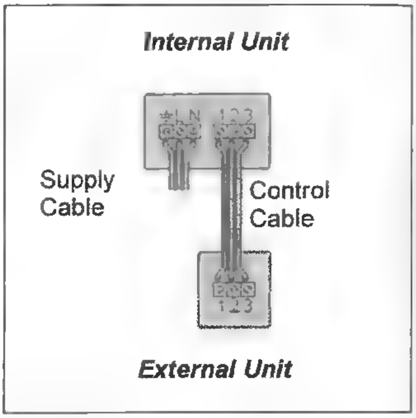
## Dimension and Weights:

Once a location has been chosen, take furniture size and door and window openings into account when installing equipment. In particular, pay attention to the width and height of a piece of equipment before deciding on its location.

Mountings must be capable of supporting the weight of the equipment (44kg for the model KOTZ 12-PA). Take the nature of the wall or partitioning into account. You won't look too clever if the equipment falls off a wall as soon as it's put into service!

## Voltage, current and electrical power:

In general terms the electrical connection of air conditioning systems is rarely a complicated matter.




Power supplies for those split systems that have a refrigeration capacity of less than 5 kW are generally single phase 220V.

The three core supply cable should be connected to the terminals marked L, N and **Earth** on the internal unit (by convention, the earth lead is bi- coloured yellow and green)

***Warning:*** **the earth connection on all air conditioning equipment is absolutely essential. Unearthed equipment could be the cause of serious accidents. It can easily result in electrocution and death!**

A control cable connects the internal unit to the external unit. Connection is usually very simple. All that is needed is to ensure that the terminals 1, 2 and 3 are **correctly** connected to each other.

That really doesn't sound so complicated. You need to be careful that the earth connections are made, but I'd soon be able to connect up this equipment!

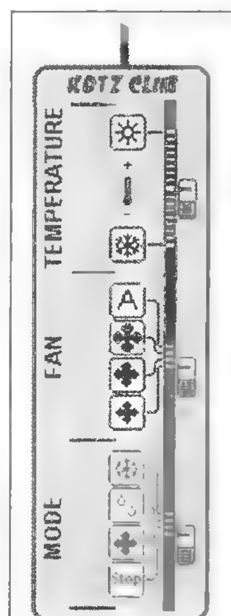
The Technical Data gives values of V (supply voltage), I (current consumed) and P (power consumption) for the Kotz 2.0-MI and Kotz 12-PI internal units.

| | Feature | Kotz 2.0-MA | Kotz 12-PA |
|---|---|---|---|
| Internal Unit | Reference No. | Kotz 2.0-MI | Kotz 12-PI |
| | Colour | Ivory | Ivory |
| | Dimensions (H x W x D) | 360x800x1200 mm | 240x1500x650 mm |
| | Weight | 9 kg | 44 kg |
| | **V / I / P** | **220V/0.17A/35W** | **220V/0.28A/55W x2** |
| | Control | infra red remote | remote cable |
| | Noise level | 36 dBA | 57 dBA |
| | Fan type | tangential x1 | centrifugal x4 |
| | Air flow LV | 3.6 $m^3$/min | 20 $m^3$/min |
| | MV | 4.7 $m^3$/min | 24 $m^3$/min |
| | HV | 5.7 $m^3$/min | 28 $m^3$/min |
| | Air Filter | Removable, washable | Removable, washable |

Electrically, the internal unit only contains the evaporator fan (note that there are two of them in the Kotz 12-PA), so the information can only be referring to the characteristics of the fan, according to the model involved. In particular, the supply voltage should be known before installation of the equipment takes place. The electrical characteristics are also often useful for maintenance and repair. It's easy, for example, to measure the current flowing using a clamp-on ammeter, and then make a comparison with the manufacturer's value. Knowledge of the power being consumed enables you to estimate the electricity being used, and hence the operating costs of the air-conditioning system.

## The remote control:

There are two types of remote control commonly in use; cable and infra-red.

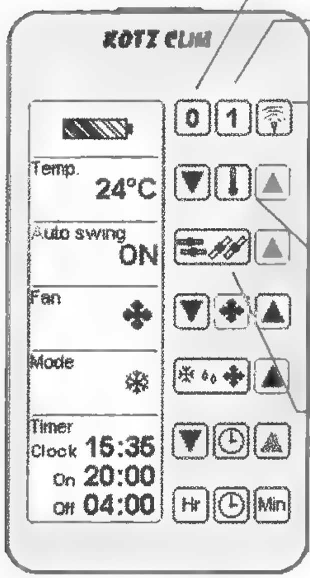



Cable controls are mostly in use with console type and ceiling mounted split systems. They are much less fashionable than their infra- red cousins nowadays, because they are permanently attached to the equipment by the control cable.

Some clients, hotel owners for example, demand that equipment be operated by means of a cable. This is to ensure that the control unit remains with the equipment, and doesn't leave the hotel in a guest's suitcase!

The sketch alongside shows us a cable remote control unit with several different functions; the thermostat function (temperature), fan speeds (fan), and the different operating modes available (mode). Some cable remote units are also equipped with a programmer (timer) allowing you to specify times when the air conditioning automatically switches on and off.

Whatever type the remote control may be, you will nearly always find that it provides the same functions. We'll examine the infra red remote below which has additional features. This control has no cable connection with the internal unit (somewhat like a TV remote control). Let's look at the various features that might be encountered in an infra- red remote control module such as this:



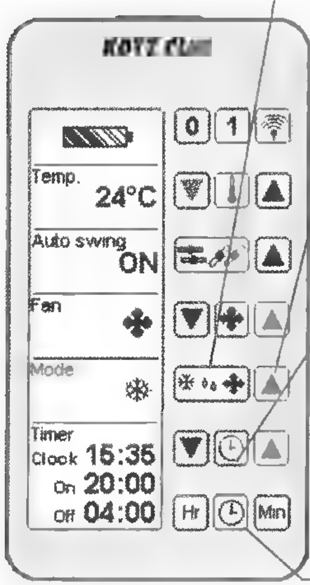

**Stop (0):** to turn the air conditioning off.

**Run (1):** to turn the air conditioning on.

**Transmit:** this control must be pressed after changes to settings have been made, so that this information is transmitted to the unit.

**Thermostat:** the temperature displayed on the remote control (here 24°C) corresponds to the selected temperature which is set using the arrows ▲ and ▼.

**Auto swing:** enables the user to control the motorised vents found at the air outflow. Pressing the arrow accesses a menu enabling the vents to be either set in a fixed position or to perform a continuous 'sweeping' motion.




**Fan:** allows the user to choose the fan speed (Low, medium, high, automatic). In automatic mode, the built in microprocessor determines the optimum fan speed from the difference between ambient and the selected temperature (the larger the temperature difference, the faster the fan speed).

**Mode:** provides a menu for choosing one of the operating modes of the air- conditioning system (see details on the following pages)

**Timer:** allows the user to programme the air conditioning start times and stop times. In the example shown the equipment is air-conditioning a bedroom, and it would be pointless to allow it to operate all day. The timer is therefore programmed to start the equipment (On) every evening at 8 p.m., and to turn it off (Off) at 4 am.

**Clock:** sets the timer to the correct time.

## Modes of operation of the A/C system:

The " Mode " button we saw on the preceding page allows the user to choose the operating mode of the system.

**The Fan function (FAN):**

When you select this operating mode, only the internal unit fan operates (the compressor does not operate). The air- conditioner simply behaves as if it were a fan circulating and filtering the ambient air in the room being air-conditioned.

**The cold Function (COOL):**

This is the operating mode most often in use. The internal unit fan operates continually in order to maintain an even temperature throughout the room being air- conditioned. The compressor only cuts in if the temperature of the room rises above the temperature set on the thermostat (24°C in the example shown).

**The dehumidification function (DRY):**

This function is not intended to provide precise hygrometric control of the room being air- conditioned. It simply prevents the humidity becoming excessive by activating the refrigeration circuit. The unit's microprocessor then maintains the best balance between dehumidification and the ambient temperature. In this mode, the internal unit fan may stop from time to time. By shutting off the fan, the microprocessor allows a drop in the LP, which causes dehumidification to occur (we'll discuss the details of this later on when we examine faults caused by insufficient evaporator capacity)

The dehumidification function is quite complicated. Should I really be able to understand all the details?

No, don't panic! Not all the manufacturers produce or control this function in the same way, anyway. So if you do actually come across a problem of this sort (which is actually rather rare) in a unit, then you should read the technical data sheets carefully.
Also, remember that if the internal unit fan isn't operating in dehumidification mode, there isn't necessarily a fault. This might save you a bit of time one day, when a client says to you "Something's wrong. The fan stops from time to time. It needs changing!"

## The heating function (HEAT):

Heating can be performed in two ways: using electric heating elements, or by reversal of the refrigeration cycle.

- *Using electric heating elements :*

The fan continually operates. The elements are under the control of the thermostat, which allows power to them when the temperature drops below the selected value. To prevent fires occurring, a safety thermostat is fitted, which measures the air temperature adjacent to the elements. If the temperature rises excessively (for example, if the fan breaks down and the elements have a voltage across them) the safety thermostat quickly cuts off their electrical supply.

- *Using reversal of the refrigeration cycle:*

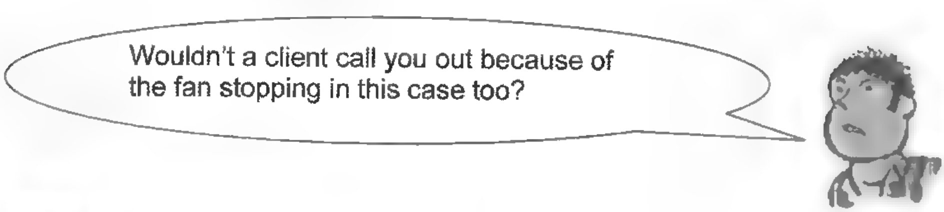
The internal unit, which is an evaporator in summer, can become a condenser in winter thanks to a small four- way valve, which we will look at closely on page 246. Heat is then absorbed from the atmosphere by the external unit (which has now become an evaporator) and discharged into the room.

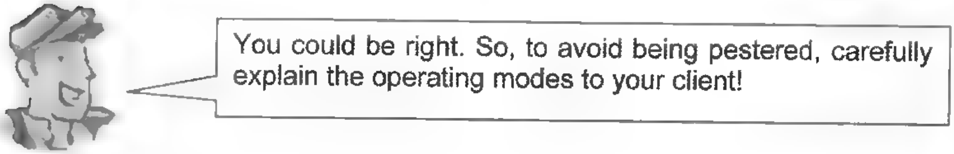
So, in the heating mode, the refrigeration cycle is reversed, and the evaporator is found outside. But remember that the evaporation temperature is the same as the air temperature at the evaporator inlet - $\Delta T_{total}$. This is why, when the outside temperature is low, the evaporation temperature falls, and the evaporator has a tendency to frost up. The microprocessor then periodically programs a defrost cycle.

To perform the defrost cycle, the four- way valve reverses the cycle once again. The heat exchanger in the external unit (which has frosted up) becomes a condenser once again (the heat influx which results rapidly causes defrosting to occur).

When this occurs, it is important to stop the fan in the internal unit (which has become an evaporator again, otherwise it will blow ice- cold air into the room. When the defrost is complete, the cycle reverses again, but the internal unit's fan will not start until the heat exchanger temperature is high enough.

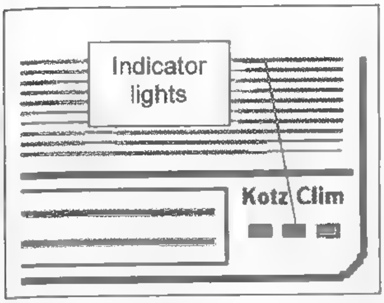
In heating mode performed by reversal of the cycle, It is quite normal for the internal fan to stop during each defrost cycle.



Most manufacturers equip their internal units with indicator lights that show the operating mode.

On reversible equipment, we often find three lights:




- Indicator for A/C mode.
- Indicator for Heating mode
- The Hot Keep indicator.

The Hot Keep indicator only lights up when the unit is in heating mode, and its function is to show that because the temperature of the internal heat exchanger is not sufficiently high, the fan is not in operation. This indicator is therefore generally illuminated during start- up of the equipment in heating mode, or during a defrost cycle.

This indicator is sometimes useful if there is a fault in the unit. For example, if there is a lack of refrigerant in the system (caused by a leak), there will be much less heat absorbed by the evaporator, and so less heat discharged by the internal heat exchanger.

The internal exchanger's temperature could then perhaps remain too low to allow the fan to start up. The Hot Keep indicator will therefore remain lit. Although this little tip isn't in itself a faultfinding procedure, it may provide an extra indication of the cause of a fault.

## Noise levels:

The noise level of air conditioning equipment is an essential feature in the provision of comfort for a client.

Let's imagine that you are approached by a client who can no longer put up with the heat, and can't open his window at night because of the noise from the traffic. As he can't sleep, he asks you to install an air conditioning unit in his bedroom. In view of his lack of money, you decide to install a bottom of the range system for him.

When the installation is finished, the equipment proves so noisy that he still isn't able to sleep. Have you, in this case, supplied him with any 'comfort'? Do you feel that he will recommend your services to others?

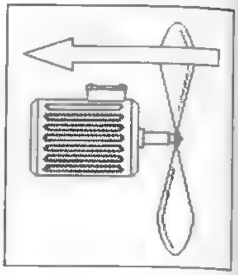
Noise levels are quoted as decibels (dbA). However, not all manufacturers measure the values they publish at the same fan speed, or at the same distance. A 36 dbA unit at low speed could be noisier than a 45 dbA unit at high speed. Never hesitate for a moment about trying to get the information you need from the manufacturer.

If the client isn't happy, remember that it's you who'll be in the firing line!

## Fans:

In 'comfort' air conditioning, you'll generally come across three types of fan: axial (or 'propeller'), tangential or centrifugal.

➢ **<u>The axial fan:</u>**

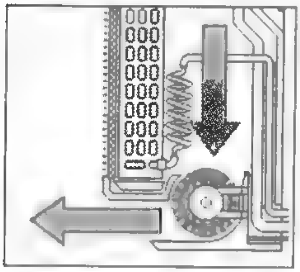


This type is used in most exterior units to ventilate the condenser.

Axial fans in general exhibit the inconvenient property of being rather noisy. To minimise this problem, many manufacturers make their fan blades from fibre composites.

The airflow produced is horizontal and rectilinear. These fans can produce large flows of air, but they only produce a relatively small air pressure. This is why they are not suitable for circulating air through a system of ducts to pass it over a condenser

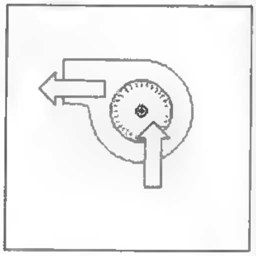
➢ **<u>The tangential fan:</u>**



This design of fan is very widely used in internal units. Its major asset is the very low noise level associated with it. It is so silent that in small A/C units (those up to a power of about 2 kW) the capillary is often even placed in the external unit. This is because the very low noise level of the fan doesn't even mask the light hissing of the capillary expansion device that occurs when the compressor starts up or shuts off.

The air flows tangentially in the fan's wheel. The flows and pressures generated are relatively low. This design of fan is not suitable for providing airflow in a ductwork system.

➢ **<u>The centrifugal fan:</u>**



In 'comfort' A/C, this design is used above all in internal units of split systems of the console or ceiling mounted types. Its principal asset is that it can produce a large enough pressure to force air through a ductwork system, or to increase the range of the airflow produced by an A/C unit (that is, the distance through which cooled air is made to travel).

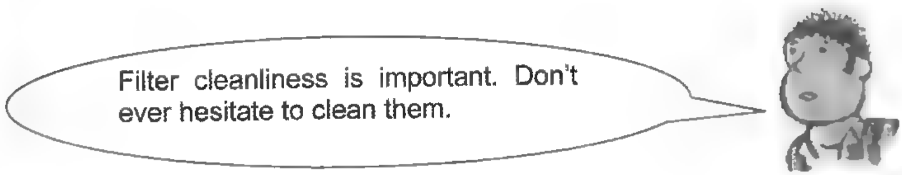
Air is drawn in through the centre of the fan then ejected through the side of the outlet of the "snail's shell". **Note:** unlike other fans, if the motor of a centrifugal fan turns in reverse, then the direction of flow will not change, but the airflow decreases greatly.

## Filters:

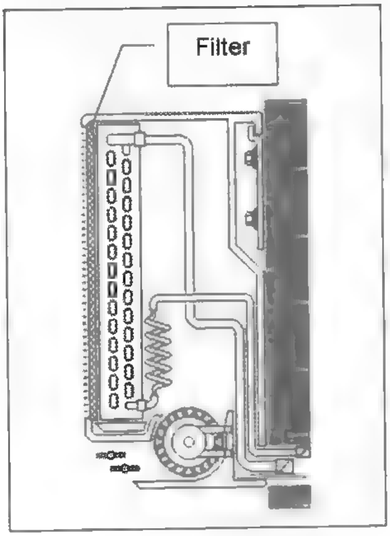
Filters fitted to air conditioning equipment are not 'super efficient' filters, capable of trapping all traces of dust.

The filter shown here, which is fitted to a wall mounted internal unit, is made up of polymer fibres. This material can be washed with water, and this should be done frequently.

A blocked air filter could result in a damaged compressor. In simple terms, let's just say that:
Blocked filter = loss of airflow = poor heat exchange between the refrigerant and the air = return of liquid refrigerant to the compressor = liquid slugging = end of the compressor.




The role of the filter is to trap dust that could seriously block the internal heat exchanger, so they're placed at the air inlet of the heat exchanger.




In order to prevent problems with vibration, manufacturers will often prefer to install several thin filters (often 2) rather than a single large one.

As you can see from the sketch opposite, filters are concealed behind the air inlet grille of the internal unit.

In wall units, they are removed by sliding them vertically downwards.

Cleaning the filters is the only maintenance task that should be undertaken by the client. He should be adequately warned about the serious problems that can arise as a result of blocked filters in his air conditioning system.

*If he doesn't want to do it himself, then you can sell him a maintenance contract!*

# TECHNICAL DATA: THE EXTERNAL UNIT

We'll now continue our study of the table on page 162 by looking at the characteristics of the external unit.

| | Feature | | Kotz 2.0-MA | Kotz 12-PA |
|---|---|---|---|---|
| External Unit | Reference | | Kotz 2.0-EA | Kotz 12-EA |
| | Colour | | Natural | Natural |
| | Dimensions (H x W x D) | | 550x750x250 mm | 1250x900x350 mm |
| | Weight | | 30 kg | 120 kg |
| | Noise Level | | 55 dBA | 60 dBA |
| | Fan | type | axial x1 | axial x2 |
| | | Air flow | 23 $m^3$/min | 88 $m^3$/min |
| | | V / I / P | 220V/0.13A/25W | 220V/0.3A/60W x2 |
| | Compressor | type | Rotary Hermetic x1 | Piston Hermetic x1 |
| | | V / I / P | 220V/2.5A/550W | 380V/6.5A/3,75kW |
| | | I start -up | 18 A | 49 A |
| | | Refrigerant | R22 | R22 |
| | | Charge | 0.72 kg | 2.8 kg |
| | | Lubricant | RV-Mineral | RV-Ester |
| | | Volume | 0.4 litre | 1.75 litre |

## Reference Nos:

As with the interior units, reference numbers are a specific "identity card" for the equipment. They allow you to order the correct spare parts when needed. The numbers are marked on the equipment and should be accurately read when they are required.

## External Units:

The overwhelming majority of external units with air cooled condensers are fitted with one or more axial fans.

However, local regulations (for listed buildings, pedestrianised areas, condominium buildings and apartments etc.) may not allow the installation of these units on the exterior. It is possible to bypass these difficulties by installing internal units with a small ducting system, so that only air intake and outlet grills are visible on the exterior. In these situations, axial fans may not be appropriate, and centrifugal fans are generally used to maintain an adequate airflow (see page 184)

Another solution is to use a water- cooled condensing unit. The heat absorbed in the air- conditioned area is then removed with the water. Be aware that although air is free, this is not the case with water!

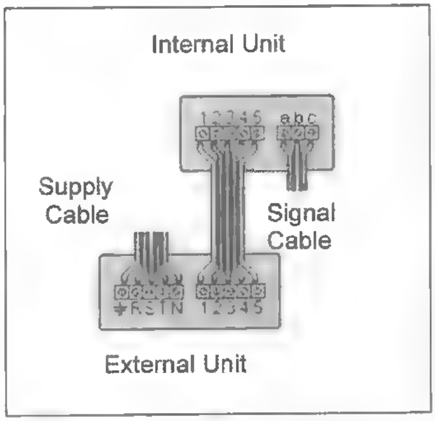
Water- cooled condensing units are outside the scope of this introductory manual, but you may find it useful to improve your knowledge of this subject using the REFREPAIR MANUAL (by the same author, pages 470 – 486).

## Dimensions, weights, noise levels, fans:

We've already covered this subject for internal units (see pages 178, 183 and 184). There isn't much to add except to say that the location and noise level factors should never be taken lightly if you wish to avoid problems with neighbours.

## Voltage, Current and Electrical power:

Split systems with a refrigeration capacity of less than 5 kW are generally designed for single phase 220V supplies. We've already seen the electrical connections for such an air conditioning unit (page178). Now, however, we should consider the situation with a three- phase supply as shown alongside.




With larger capacity systems, the use of three- phase 380V supplies becomes necessary. The supply cable then has 5 leads to connect to the external unit terminals; R, S, T, N and Earth. By convention, the N (neutral) wire is blue in colour, and the Earth a twin coloured green and yellow). The other three wires correspond to the three 380V phases.

A signal cable connects the internal unit to the external unit. The wiring is generally quite simple. All that is required is to connect the same lead between terminals bearing the same number (terminal 1 to terminal 1, terminal 2 to terminal 2 etc.)

Finally, if the unit is fitted with a cable remote control, it should be wired into the interior unit (for example to terminals a, b, c). The number of leads may vary according to the manufacturer, but they should always be identified for connection by labels or a colour code. In all cases, it is essential that you follow to the letter the wiring instructions supplied with the equipment.

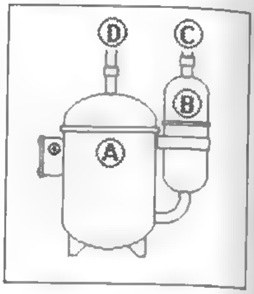
With regard to the electrical side of things, it is, of course vital to know the supply voltage that will be available at the client's premises. It's much better to find this out when you are preparing the quotation, than to find yourself trying to install three- phase 380V equipment using a single phase 220V supply! Naturally, any self- respecting engineer would test the supply voltage before connecting equipment to it. Connecting a 220V unit to a 380V supply would instantaneously "cook" it!

The quoted values for electrical characteristics of the fan and the compressor are often useful for maintenance purposes. Using a clamp- on ammeter, it's easy to compare the current actually flowing with the quoted values. Finally, knowing the power consumed you can estimate the electricity being used, and therefore the operating costs of the air- conditioning system.

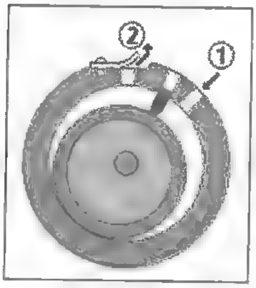
## Rotary compressors:

Up to this point, in order to simplify our explanations, we've been using hermetic piston compressors. However, The majority of 'comfort' air-conditioning systems today are equipped with hermetic rotary compressors.

The diagram opposite shows us an external view of such a compressor. The term "hermetic" indicates that the compressor and its motor are enclosed in a gas tight container or "pot" (A), and are therefore not repairable. If a problem occurs, the whole unit must be replaced. Since these compressors can't cope with the dreaded "liquid hammer", they are automatically equipped with an anti-slugging liquid receiver on the suction side. (B). Note that the refrigerant enters at ('C') and is discharged at ('D') after compression.

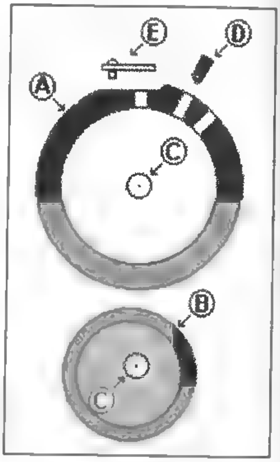



The term 'rotary' indicates that compression is caused by a rotary motion, rather than the classical translation (i.e. backwards and forwards) motion of a piston.




On the left we can see a simplified section of a rotary compressor. Refrigerant is drawn in at 1 and is discharged at 2.

It is made up of the following components:




- Item A: the stator is the fixed part of the compressor.
- Item B: The "rolling piston" or, as it is sometimes called, the "turning piston" or "eccentric".
- Item C: The shaft lies along the same axis as the stator (top diagram) but is out of line with the centre axis of the rotating piston (bottom diagram). Rotation of the shaft is caused by an electric motor.
- Item D: a sliding plate maintains full separation between LP and HP. It is kept in continuous contact with the rotating piston by means of a spring-loaded mechanism (not shown).
- Item E: the discharge valve.

The rotary compressor exhibits many advantages in comparison to its reciprocating piston counterpart. There are fewer moving parts, making it more reliable, less noisy, lighter and more energy efficient.

However, this design is mostly limited to air- conditioning units with a cooling capacity of less than about 7 kW.

*Why not spend a little time thinking about the operation of this type of compressor before we continue?*

## The Operation of the Rotary Compressor:

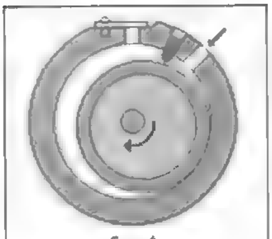


fig. A

Figure A:
The drive shaft causes the moving piston to rotate. The stator remains fixed. The volume of the LP chamber starts to increase.

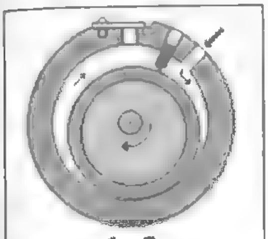


fig. B

Figure B:
The piston continues to rotate. The volume of the LP chamber continually increases and draws in vapour. At the same time the volume of the HP chamber decreases. The pressure of the vapour trapped in this chamber continually increases. For the moment, the discharge valve reed remains closed.

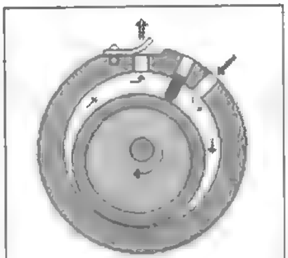


fig C

Figure C:
Vapour continues to be drawn into the LP chamber, whose volume continually increases. At this point the reduction in the volume of the HP chamber results in a pressure increase sufficient to cause the discharge valve reed to open.

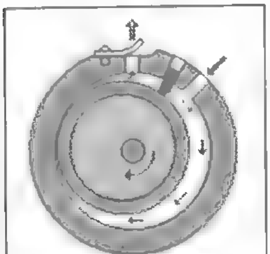


fig. D

Figure D:
The LP volume continues to increase, and the HP volume to decrease. Refrigerant continues to be drawn in, whilst the compressed and superheated HP vapour is discharged through the discharge valve.

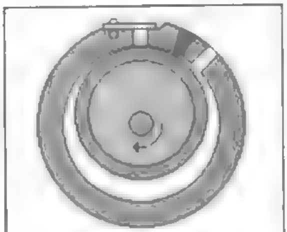
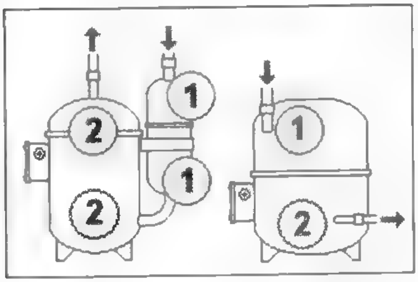


fig. E

Figure E:
The LP chamber volume is at its maximum, and the HP at its minimum. Both intake and discharge of refrigerant stops.

The rotating piston has completed one full rotation, and starts another cycle as in figure A above.



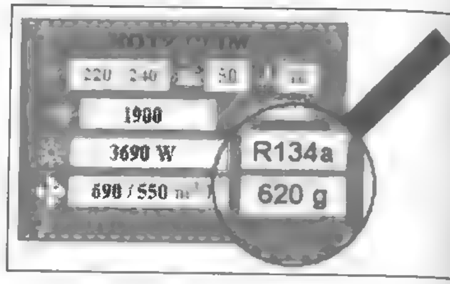

The major difference between a rotary compressor (on the left) and its piston counterpart (on the right) is obvious. Rotary compressors are smaller in dia-meter, and are always equipped with an anti- hammer suction line accumulator.

**Also note that in normal operation, all parts indicated as 1 are rather cool, and those indicated as 2 can be *very hot:* take care then, as the entire pot can be boiling hot with a rotary compressor...**

In all other respects, both types of compressor do exactly the same thing; they draw in LP vapour and discharge it as HP. Thankfully, the refrigeration circuit is, of course, the same whichever type of compressor is being used. It is interesting to note that the motor is cooled by the refrigerant itself, by the LP vapour in reciprocating compressors, and by the HP vapour in rotary compressors.

## The Refrigerant used:

The type and quantity of refrigerant used in the equipment is always shown on the identification plate.




Looking at the plate opposite, we can observe that the equipment contains 620 grams of R 134a. This information is very important for a number of reasons:

- In some EU states, non- registered engineers can only work on systems with less than 2 kg of refrigerant. Above this charge size, only registered engineers may work with the systems. Registration is controlled by authorised bodies.

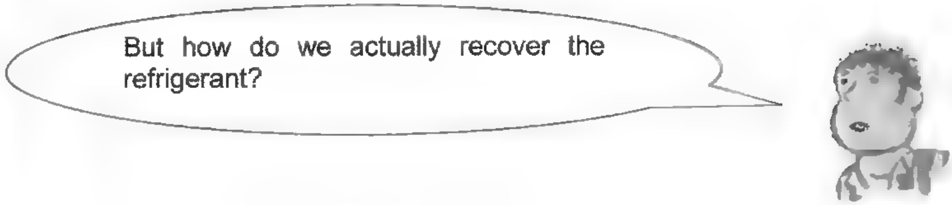
  In this new century, these regulations will be tightened even further. It is very likely that handling refrigerants at all will be forbidden for non- registered individuals.

- It is not easy to 'top up' the refrigerant charge in a system equipped with a capillary expansion valve. The refrigerant type and mass of refrigerant in a system is critical, and must be absolutely correct. If establishing the refrigerant type is easy enough (you only need to read the identification plate), how can you know the amount of refrigerant that is still in a system?

  The answer is to completely empty the system using a recovery set, and then re- charge it with **good quality refrigerant** using the **exact quantity indicated** on the plate. This is the only way to ensure that the refrigerant charge is absolutely correct.

Do we really have to do all that?

You'll see that when there has been a refrigerant leak, completely recharging a system will in actual fact save you time!




This subject is discussed in detail in the REFREPAIR MANUAL (by this author, pages 391 to 404). This 626-page manual, which is entirely concerned with repair and fault- finding, will enable you to considerably broaden your knowledge of refrigeration systems, once you have completely mastered this manual.

## Refrigeration Oil:

Whatever the design of the compressor may be, all its moving parts need lubrication using a suitable oil, which, in addition, must be compatible with the refrigerant used. Refrigerants have no lubricating properties, but are, on the contrary, excellent detergents which will clean lubricants from mechanical parts. The problems associated with lubrication are usually quite complex.

- Oils and refrigerants must not attack each other. This means that manufacturers must use *different types of* oil according to the refrigerant used and the operating conditions.

**Different oils should never be mixed in the same installation. Different refrigerants should never be mixed in the same installation. Both these situations will result in the death of the compressor in double quick time!**

- Refrigerant oil is very hygroscopic. This means that it will quickly absorb the moisture contained in air. The biggest problem arising from this is that an oil that has absorbed too much moisture could become acidic and lose its lubricating properties.

**Never allow oil to remain in contact with air. There must never be the slightest trace of water in a refrigeration system.**

Oil-cans should be sealed immediately after use. Similarly, a refrigeration system should never be left open to the atmosphere since even if it contains no refrigerant, as there will always be oil inside it.

- Oil doesn't sit quietly in the compressor crankcase. It passes out through the discharge pipework and flows around the whole system. This isn't such a problem if the oil that leaves can return freely to the crankcase. So follow the manufacturer's recommendations carefully if you want to avoid problems.

**Always follow installation instructions to the letter!**

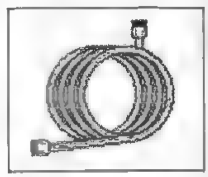
# VARIOUS TYPES OF CONNECTIONS

We'll complete our study of the Technical Data by reading manufacturers' advice about the various types of connections.

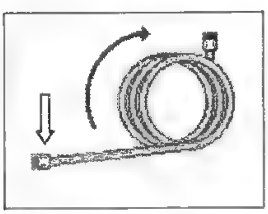
| | Feature | Kotz 2.0-MA | Kotz 12-PA |
|---|---|---|---|
| Connections | Liquid pipework | 1/4" | 3/8" |
| | Gas pipework | 3/8" | 3/4" |
| | Connector Type | Quick | Flare |
| | Maximum pipe length | 10 m | 25 m |
| | Maximum height diff. if : | | |
| | Ext. Unit higher | 5 m | 20 m |
| | Ext. unit lower | 5 m | 15 m |
| | Pipework insulation | Gas and Liquid | Gas and Liquid |
| | Condensate Drainage | ∅16 mm | ∅ 24 mm |
| | Supply Cable | 3G2.5 | 5G2.5 |
| | Signal Cable | 3G1.5 | 8G1.5 |

## Refrigeration Grade Pipework:

We saw in the previous chapter that moisture should never be allowed into a refrigeration circuit. It's for this reason that we must use refrigerant grade copper pipework. The refrigerant tubing supplied with the equipment is wound into a coil, and sealed at both ends to protect the interior.



The internal surfaces of the tubing are *polished* and then *dried* during manufacture. In comfort A/C, we will normally use tubing of one of five diameters: 1/4″, 3/8″, 1/2″, 5/8″ and 3/4″. These dimensions are the external diameters of the tubes (and inches are still used!). Remember that 1″ = 25.4 mm.



In order to use the copper pipe, we first of all unwind the coil carefully, as shown in the sketch alongside. It should be slowly unrolled onto a flat floor, and the straight length obtained in this way kept in place on the ground using the feet.

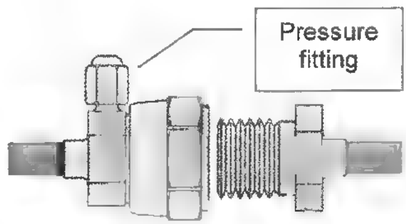
Following this, before connecting the units to each other, the piping should be prepared and angles made to allow the pipework to follow the desired routing. Angles can be made around a curved surface or by using a bending spring appropriate for the diameter of the tube in use.

Bending by hand is not recommended, especially for those angles of small radius that are needed where the pipework emerges from walls. It is easy to flatten the tubing unintentionally, which will greatly hinder the flow of refrigerant in the tubing. Problems arising from this could appear as soon as the equipment is put into service.

Refrigeration connections between the two units are made using lengths of tubing: the *liquid pipework,* connecting the condenser outlet to the expansion device inlet, and the *suction pipework* connecting the evaporator outlet to the suction side of the compressor. These are of different diameter. The smallest carries the liquid and the largest carries the gas (for a given mass, since the gas occupies a greater volume than liquid, it needs a larger diameter pipework.)

## Refrigeration Connections:

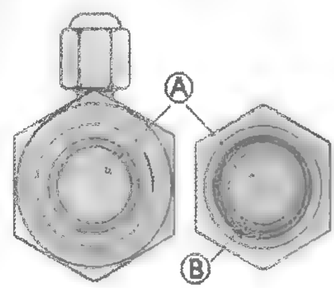
Two types of connections are in use, commonly called 'quick' and 'flare'.




### Quick Connections:

Quick connections, (so called because of their ease of assembly) are made up of male and female parts that can be screwed together. A pressure fitting, to allow a gauge to be connected is present on some types.

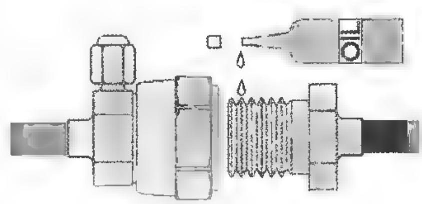
**This type of connection is found where the connecting pipework is supplied pre- charged with refrigerant.**



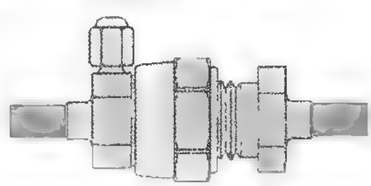

A metallic membrane on each connection (A) helps maintain the gas- tightness of pre-charged tubing. As the connection is tightened, the membrane is broken, and this allows the refrigerant to pass. Pre- charged pipework also has the advantage of allowing us to avoid numerous refrigerant-handling steps during an installation.

As the joint is tightened, an O-ring (B) provides a gas- tight seal. Note that the membrane is pierced on tightening. If you then unscrew the connection, you will lose refrigerant, so that these connections cannot be broken whilst there is still refrigerant in the system.

To avoid problems at the time of connection, It is strongly recommended that you observe the following procedure:




- **Prepare the pipework** and ensure that the male and female connections are perfectly aligned.
- **Remove the plastic caps** protecting the ends of the tubing.
- **Place a few drops of refrigeration oil** on the threads and the O-ring.
- **Hand- tighten the connection.** If you can't, then it's due to misalignment. Never use a spanner at this stage!



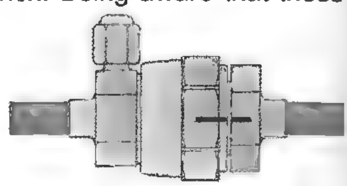
Final gas- tightness is achieved via. the tapered thread. If you damage the thread, the pre- charged tube and its 'quick' connections become useless.

- When the metallic membranes come into contact with each other, you'll feel a resistance, and you won't be able to hand tighten any further. At this point the pipework and the units are once more gas tight, but we haven't finished yet.

- To rupture the membranes, continue to tighten the connection using a pair of spanners, one on each part of the connection. This will prevent the male connection turning, and so twisting the copper tube. During this operation, the membranes rupture, and the gas-tight seal is maintained by the O-ring (which is why it needs to be well oiled at the start).

> *If, during tightening, you discover that the connection is leaking, above all, don't stop tightening. As the membranes have been pierced, any unscrewing of the joint will cause the leak to increase. Since the final gas tightness will rely on the taper of the thread, you must continue to tighten the connection.*

- When the tapered threads meet, you will feel a resistance. The final tightening should be made using a torque- wrench. Being aware that these tools may not always be available, several manufacturers provide marks on the connections as indicated. Final tightening is made by performing a further quarter turn once these marks are in alignment. The screw connection is then complete.



- **Always test for gas- tightness after connections have been completed.** If you haven't access to a suitable leak detector, you can perform this test using soapy water.

Although pre- charged pipework has the advantage of allowing you to avoid any refrigerant handling, it is inconvenient in that it isn't always of the correct length. Sometimes this can be overcome by moving the units slightly to adjust the length required.

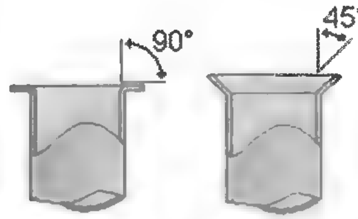
There is another type of connector available (the 'flare' type) that allows tubing to be cut to the correct length. Since this involves performing operations on the refrigeration circuit, a degree of competence in these activities is required.

A choice between 'quick' or 'flare' connections isn't always possible. Manufacturers rarely offer both types of connections in their ranges of equipment.

Several years ago, the trend was to use all 'quick' fittings. Today, the trend is towards 'flare' fittings. Things may change again, but in repair work, you will almost certainly have to deal with all types of connections.

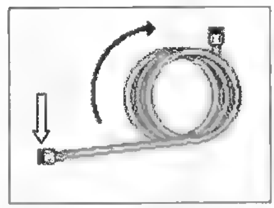
## The flare connection:

This type of connection uses a special nut in conjunction with a flared out tube end, sometimes called a dudgeon. It is a kind of refrigeration "flange", but with the following peculiarities:

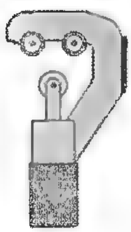



- The angle produced in a flanged tube is 90°, but 45° for the flared dudgeon.
- The seal in a flare connection is made between the flared copper tube end and the tapered face of the connector (unlike a flange fitting, there is no gasket).

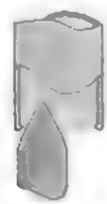
To prepare a flare connection, you must follow this procedure:



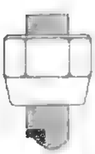
- Unroll the coil of tubing following the directions on page 192.



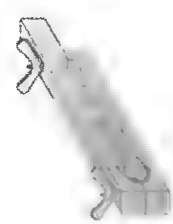
- Cut the required length using a tubing cutter (never use a saw for this). Do this slowly and gently to avoid crushing the tubing.



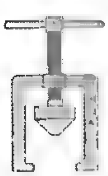
- De-burr the tube end, with opening downwards, so that the swarf doesn't fall in. To prevent the tube splitting as it is being flared, avoid scratching it, or making cracks or splits as you de- burr it.



- Above all, don't forget to pass a flare nut onto the tube before you flare it. If you don't, you'll have to cut the tube again, and start all over!

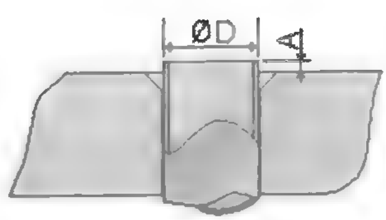


- Locate the cut tubing in the flaring tool. This has a die, which has been specifically designed for refrigeration tubing.

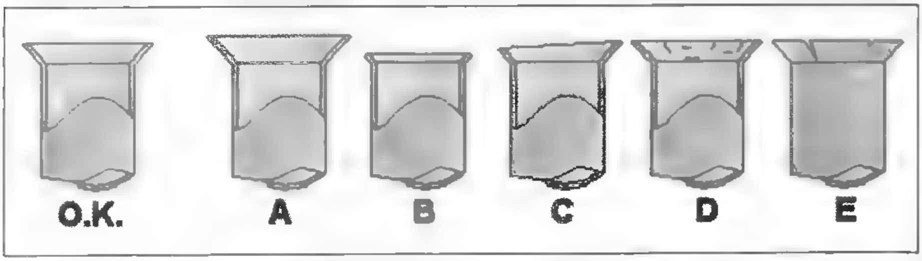


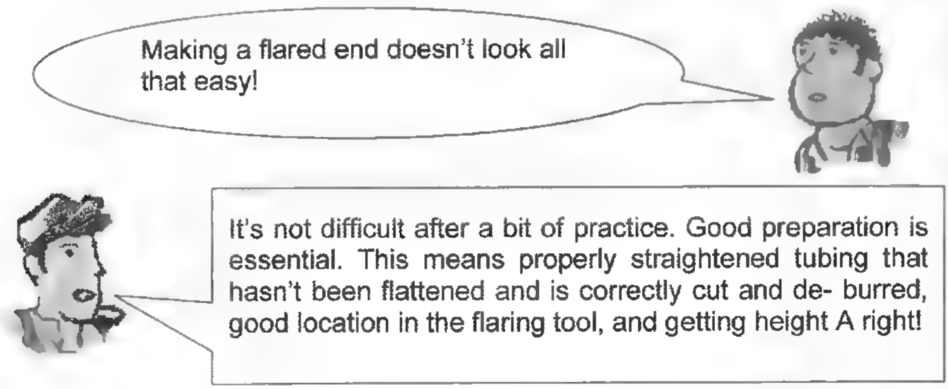
- Tighten the jaws of the die, allowing a height **A** of tubing to emerge above the die. This gives the correct flare length. The final forming of the flare is made by carefully screwing the forming tool into the tubing end.

| *Tubing Diameter* | *1/4"* | *3/8"* | *1/2"* | *5/8"* | *3/4"* |
|---|---|---|---|---|---|
| **HeightA ( mm )** | **1.3** | **1.6** | **1.8** | **2** | **2.2** |



- Check the quality of the flared tube end that you've prepared:
    - *If it's too large (fig. A),* it will be difficult, or even impossible to tighten the flare nut. The copper won't be compressed correctly as it's tightened. A leak is certain.
    - *If it's too small (fig. B),* It will be very weak after tightening, and it could break off at any time.
    - *If it's at an angle (fig. C),* the flare width is irregular, too small on one side, and too large on the other. This flared end will be fragile, and could possibly leak.
    - *If it's scratched or grooved (fig. D),* this is a warning sign of future splits.
    - *If it's split (fig. E),* It is likely to leak or break off.

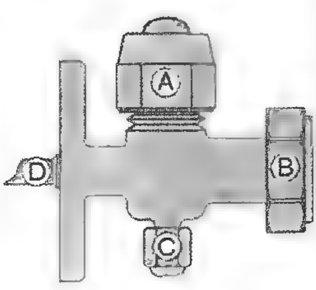



**Working with copper tubing and making the various connections associated with refrigeration pipework are the only parts of the fridge circuit that can't be completed in the factory. The life- span of an A/C system essentially depends on the quality of this work.** If necessary, practice making flared ends on scraps of copper tubing. Practice makes perfect!

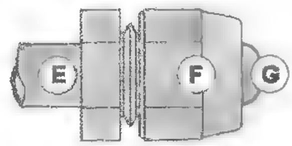
**<u>At the External Unit End</u>, there is a service valve fitted** with:

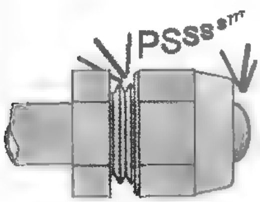
- A flare nut, (A) to fit onto the tube before making the flared end.
- A cap (B) which allows access to the valve stem.
- A pressure fitting (C) to allow connection of gauges.
- Connection to the refrigeration circuit of the external unit is already made in the factory (D).



**Note: The valve must be absolutely shut** (in the delivery position) before unscrewing the nut (A). If it isn't, all the refrigerant charge contained in the external unit could escape.

<u>**At the Internal Unit End,**</u> The male threaded connector is brazed onto a copper pipe (E). It is supplied with a nut (F), which again should be fitted over the tubing before completing the flared end. The copper end- cap (fig. G) plays an important role.




When leak tests are performed in the factory, the interior unit is pressurised with nitrogen. You need the to remove nut (F) to use in making the flare connection. When you unscrew it, take care not to twist the copper pipe (use a pair of spanners). As you unscrew the nut, you will hear the nitrogen escaping. Don't panic, it's a nitrogen leak, not a refrigerant leak!

You should be concerned if you <u>don't</u> hear the nitrogen escape. This would indicate that there is a leak in the internal unit somewhere. The seal at the end- cap (fig. G) is made using a capsule of copper, which has been flared. If you want to know what a flare should look like, then examine this cap!

**From the connections used, you can see that the internal unit contains nitrogen, and that the external unit contains refrigerant. The isolating valve allows the pipework to be connected without losing refrigerant.**

So, Charlie, do you understand the differences between 'quick' and 'flare' connections?

Both are screw- threaded connections, but 'quick' are found with pre- charged pipework, whereas 'flare' are used with 'classic' refrigeration pipework.

That's exactly right! You could also say that making 'flare' connections involves many more operations, and shows that you are a competent refrigeration engineer.

## Refrigeration Pipework:

| | Feature | Kotz 2.0-MA | Kotz 12-PA |
|---|---|---|---|
| Connections | Liquid pipework | 1/4" | 3/8" |
| | Gas pipework | 3/8" | 3/4" |
| | Connector type | Quick | Flare |
| | Maximum pipe length | 10 m | 25 m |
| | Max. height diff. If | | |
| | Ext. unit higher | 5 m | 20 m |
| | Ext. unit lower | 5 m | 15 m |
| | Pipework Insulation | Gas and Liquid | Gas and Liquid |

### Diameters:

Pipework diameters depend on the cooling capacity of the unit, and the physical state of the refrigerant flowing through them. The greater the capacity of the system, the larger the quantities of fluid that are in circulation and the larger the diameter of the pipework that is needed. In addition, as stated earlier, for a given mass, vapour occupies a greater volume than liquid and so gas pipework should be of much larger diameter than liquid pipework.

### Pipe Lengths:

On all installation instructions supplied with equipment, the manufacturers specify maximum pipework lengths and the maximum height differences that can be used. If these directions are not followed, the supplier's guarantees become void.

The problems involved mainly concern the refrigeration oil that circulates in the equipment used in the installation, and which must be returned to the compressor. As a manufacturer cannot know in advance the length of the pipework that you will need to use for the installation, he will calculate the diameters for a maximum pipe length.

So, as long as you follow the directions regarding distances and height differences, there won't be a problem. Refrigerant flow will be sufficient to ensure the circulation of the oil, and its return to the compressor crankcase.

If pipework lengths are too great, they will provide a significant resistance to the passage of refrigerant, and its flow- rate will diminish. As the flow diminishes, the circulation of refrigerant slows, and oil return to the compressor becomes difficult. Oil will then become trapped in various parts of the system instead of returning to the crankcase where it is needed to lubricate the compressor.

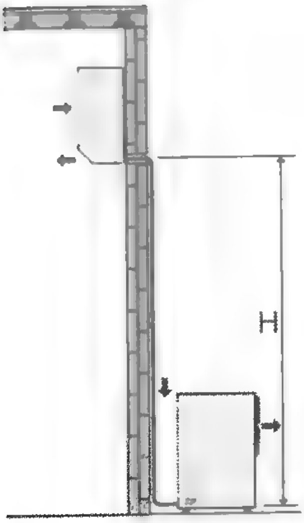
In addition, since the flow of refrigerant at the evaporator is reduced, the cooling capacity decreases and the superheat increases. The temperature of the vapour drawn in by the compressor increases, and cooling of the compressor motor is less effective. This could present a problem for the electrical windings of the motor.

**Pipework too long = poor lubrication and poor cooling of the compressor.**

## Height differences:

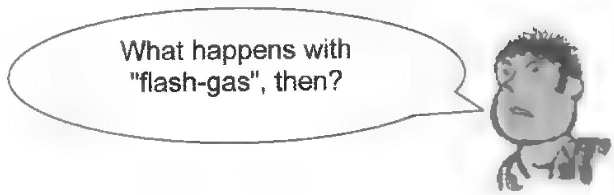
This is the oil- return problem again, to which we must add the problems of pre- expansion known as "flashing" or "flash-gas", which imposes a maximum height difference between the two units.

There are two possibilities: The internal unit is located above the exterior unit, or the reverse is possible.




In the case shown in the figure opposite, the oil has no difficulty in returning to the compressor. Since the suction side pipework flow is downwards, it will return under gravity.

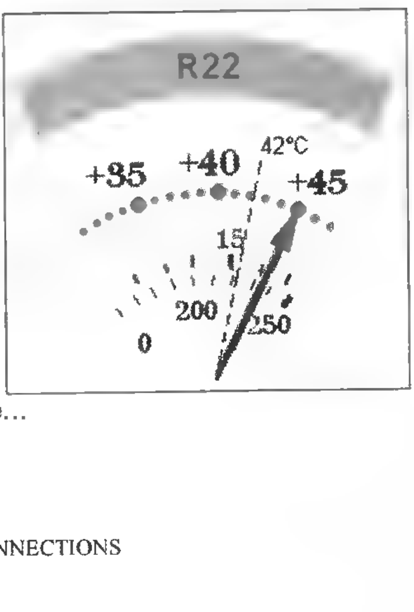
Unfortunately, another problem arises. The liquid pipework is rising, and at the top of the column of liquid, the pressure is less than that at the bottom. This means that there is a possibility of "flash-gas" being produced.




## What is "Flash-gas"?

Basically, the term "flash-gas" or "flashing" refers to the situation where the refrigerant expands *before* it gets to the expansion device. Then, instead of arriving at the expansion device inlet as 100% liquid, the refrigerant is already in the form of saturated vapour. As less liquid arrives at the evaporator, it cannot absorb so much heat. The immediate consequence of flash-gas being produced is therefore a fall in the refrigerating capacity, and hence an unwanted increase in the temperature of the room being air- conditioned.

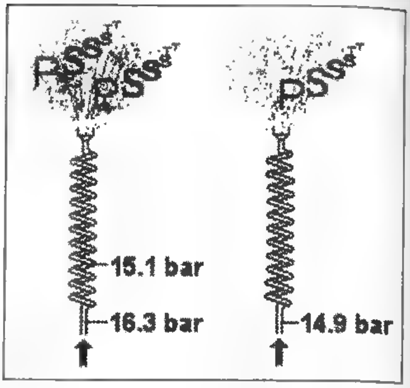
## How is flash-gas produced?




With a condensation temperature of 45°C, the HP is 16.3 bar. With sub- cooling of 3°C, liquid emerges from the condenser at 42°C.

As the pressure- temperature relationship shown opposite indicates, we should see a pressure of 15.1 bar at 42°C. *If the pressure of the liquid anywhere in the liquid line falls below 15.1 bar*, then some liquid will be forced to evaporate. If this occurs, we say that "flashing" has taken place...

Note that liquid R22 starts to evaporate as soon as its' pressure falls below 15.1 bar.



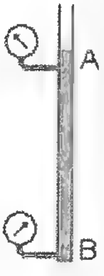

**If it arrives at the expansion device inlet at 16.3 bar, the R22 at 42°C is 100% liquid. Evaporation will only start when the expansion device lowers its pressure to less than 15.1 bar. *This should only occur inside the capillary.***

If it arrives at the capillary at a pressure less than 15.1 bar (say, 14.9 bar), it must be already partially vaporised. There will then be less liquid, and more vapour at the evaporator inlet. Hence the cooling capacity will be decreased as the size of the pre- expansion effect that produced the flash-gas increases.

**<u>What causes the pressure drops?</u>**

Pressure drops in a system are caused by the pipework and by the other equipment found in the refrigeration circuit. Each time the refrigerant enters an element of the refrigeration circuit, (whether this is a length of pipework, valve, filter- dryer, heat exchanger etc.), this element provides a resistance to the passage of the refrigerant, and the pressure falls slightly. This pressure loss is sometimes called a "loss of head". This simply means that the refrigerant pressure has dropped.

Height differences can also cause a pressure drop.




In a column of liquid, the pressure is higher at the base of the column than at the top. If you recall our diver, the deeper he went, the greater that the pressure that he experienced became, because the pressure was caused by the column of water above him (see page 28). It's exactly the same in this example. The pressure at B is greater than the pressure at A, the difference simply being due to the weight of the column of liquid.

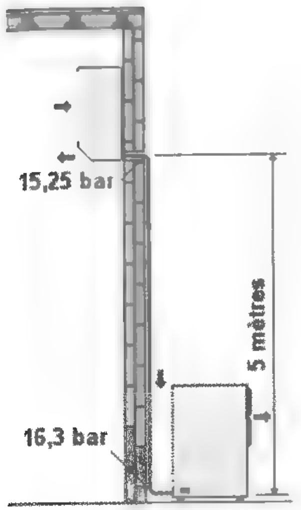
***A 1 metre high column of R22 exerts a pressure of about 0.12 bar.***

If the height difference between A and B is 5 m, the pressure difference is therefore 5 m x 0.12 bar, that is 0.6 bar. That is: $\mathbf{P_B = P_A + 0.6}$ **bar**, or $\mathbf{P_A = P_B - 0.6}$ **bar.**

In the liquid line of the Kotz 2.0-MA air conditioning system (see page 198), there are therefore the following pressure drops:

- The filter- dryer: let's say a mean pressure drop of 0.2 bar.
- The length of pipework: with a maximum of 10 metres, the pressure drop might be calculated as being about 0.25 bar.
- The liquid column: with a height difference of 5 metres, the pressure drop would be 5 x 0.12 = 0.6 bar between the bottom and the top of the column.

In total, the fall in pressure is therefore 0.2 + 0.25 + 0.6 = 1.05 bar. That is to say that the pressure at the inlet of the expansion device is only 16.3 – 1.05 = 15.25 bar.

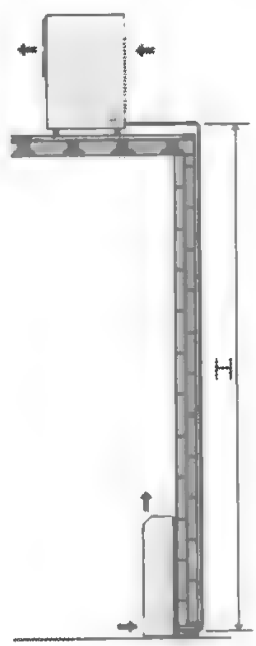



To prevent flash-gas being produced in our example, the pressure must never fall below 15.1 bar. We are therefore close to this limit, and we could not use pipework longer than this, or a height difference greater than this. *So always stay within the manufacturer's limits.*

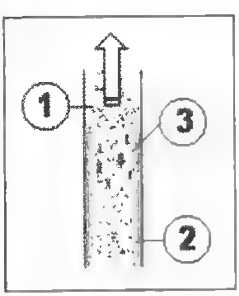
*Above all, where the internal unit is located above the external unit, never exceed the maximum height difference specified by the manufacturer, unless you wish to produce flash-gas.*

Note that if there is flash-gas produced, the liquid starts to vaporise in the liquid line and absorb heat. ***You will, therefore, be able to observe a characteristic temperature difference between the bottom and the top of the liquid line.***

Where the internal unit is located below the internal unit, there will be no problem with flash-gas. The liquid will be falling, and the pressure at the expansion device inlet will therefore be greater than that of the liquid emerging from the condenser.




Unfortunately for us, another problem arises in the suction side pipework. Although the oil leaving the external unit can easily flow down the liquid line here, it still has to ascend the whole length of the suction side pipework in order to return to the compressor!




Be aware that it's the high velocity of the refrigerant vapour (fig. 1) in the suction line that causes the oil (fig. 2) to flow upwards, and that this velocity is around 5 metres per second.

However, if the height difference is too great, the oil will not be carried upwards, despite the refrigerant's velocity. It will detach itself from the tubing wall, and, falling under gravity, accumulate in the bottom of the pipework. Once again, this can cause us problems.

***You can avoid these problems if you carefully follow the manufacturer's recommendations for maximum pipe lengths and height differences.***

## Pipework Insulation:

To prevent condensation problems and loss of cooling capacity, suction line pipework should be insulated. In certain cases, we will see that insulation of the liquid line can also prove indispensable. Let's look now at each of these two lines of pipework.

### The suction side line:

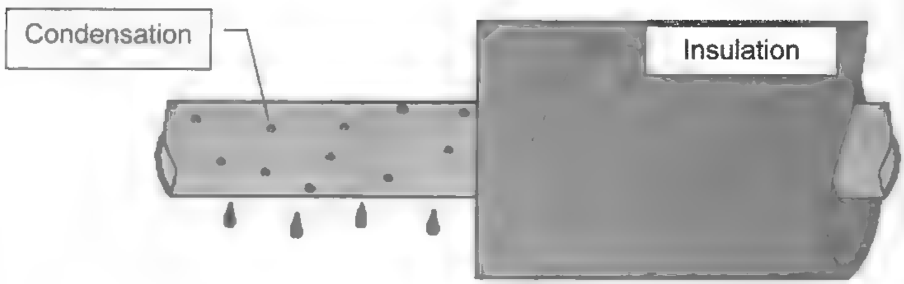
The suction pipework brings the refrigerant vapour from the evaporator to the compressor. It is, therefore, the larger of the two lines of pipework. Do you remember how to calculate the temperature of this line?

$T_0 = T_{ambient} - \Delta T_{total}$ (between 16 and 20°C) $T_{suction} = T_0 +$ superheat (between 5 and 10°C)

*For example, with an ambient temperature of 23*°C, we would obtain:

$T_0 = 23°C - 18\ °C$ ($\Delta T_{total}$ mean) = 5°C.
$T_{suction} = 5°C\ (T_0) + 7°C$ (mean superheat) = about 12°C.

The surface temperature of the suction line is therefore around 12°C, which means that the water vapour in surrounding air condenses readily.




To prevent condensation and all the problems that it causes, the pipework must be insulated. Note that insulation should cover all the pipework, as well as all the connections to the external unit. Lengths of insulation sleeving should be glued together where they meet to prevent the infiltration of air, which would cause condensation.

With reversible A/C equipment, in winter the vapour line carries very hot gas discharged by the compressor. Since the objective is to heat a room, we must try and limit heat losses in the pipework, so it is equally important to insulate the larger pipework.

Before we finish, all we have to do is ask ourselves some questions:

**Whatever the type of A/C system involved, the gas line (i.e. the widest diameter pipe) should be insulated.**

## Must we insulate the liquid line?

The liquid pipe- work (the smaller of the two lines) brings sub- cooled liquid from the condenser to the evaporator. Should it be insulated? If it isn't, there are two possibilities: thermal exchange with the air will increase the temperature of the liquid (if the air is warmer) or lower it (if the air is cooler).

> *What is the temperature of the liquid?*

The refrigerant emerges from the condenser as a sub-cooled liquid; that is, its temperature corresponds to the condensation temperature ($T_K$) minus the value of the sub- cooling (SC). Can you remember how to evaluate the temperature of the liquid?

$T_k = T_{exterior} + \Delta T_{total}$ (about 15°C) $T_{liquid} = T_k$ - SC (about 5°C)

*For example,* with an external temperature of 30°C, we obtain:
$T_K$ = 30 + 15 ($\Delta T_{total}$ mean) = 45°C  $T_{liquid}$ = 45 ($T_k$) – 5 (SC mean) = 40°C.

We can therefore say that the sub- cooled liquid is at a temperature that is about 10 to 12 degrees above the external temperature.

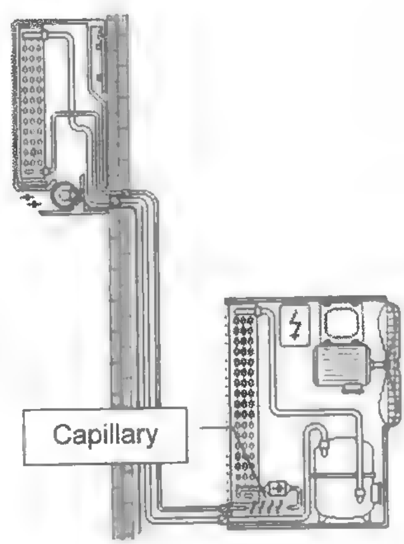
> *How does the thermal exchange occur?*

This is always from the hotter body towards the colder one. This is why, if the external temperature around the pipework is lower than that of the liquid, then sub –cooling continues, and there is no risk of flash-gas.

On the other hand, if the external temperature is greater (pipework is exposed to the sun, or passing close to a source of heat e.g. an oven, a boiler room etc.) the temperature of the liquid will rise, and flashing could occur. In this situation it becomes essential to insulate the liquid line.

> *Where is the expansion device installed?*

The capillary produces a slight hissing sound when the compressor cuts in and out. Since the noise level associated with a tangential fan isn't loud enough to mask this noise, some manufacturers install the expansion device in the external units of small capacity equipment (frequently used for bedrooms).



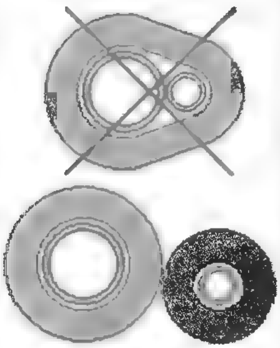

In these cases, saturated vapour and liquid, (which is cold) emerges from the external unit.

It is essential, therefore, to insulate the narrower pipework if we don't want the liquid to be completely vaporised before it gets to the internal unit!

➢ *Reversible air- conditioning systems:*

In heating mode, the external unit serves as an evaporator. As the expansion valve is generally located in the internal unit, the liquid line carries very cold vapour in this case. It would therefore be preferable to insulate it in order to avoid condensation problems (these systems will be examined on page 246).

➢ *How do we insulate pipework?*



*To prevent an unwanted exchange of heat between the liquid line and the vapour line, they should always be individually insulated.*

The situation alongside, with both pipes placed together inside the same insulation tube must never occur.

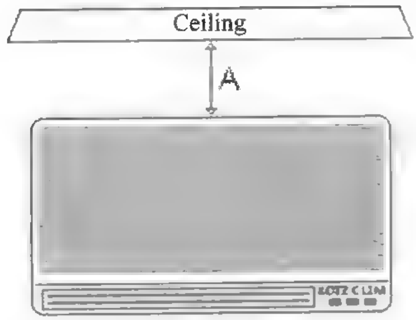
**In summary, then, the two sets of pipework should always be insulated, except in the case of a "cooling only" system where the expansion valve is located inside the internal unit, and where there is no possibility of undesirable heating of the liquid line.**

## PERSONAL NOTES

# INSTALLATION OF A SPLIT SYSTEM UNIT

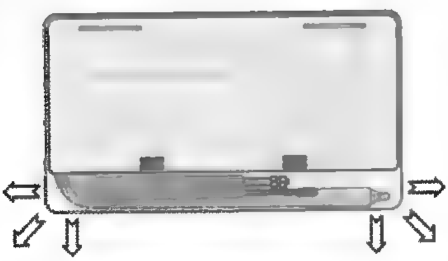
You should now have a better understanding of the technical data provided regarding capacities, the internal unit, the external unit and the various connections. Now let's consider the installation of our split system.

## Installation of the internal unit:




Consider the wall unit opposite as an example. Once its location has been agreed it should be located at a height that ensures good circulation of air in the room. Also make sure that the minimum distance A specified by the manufacturer is observed.

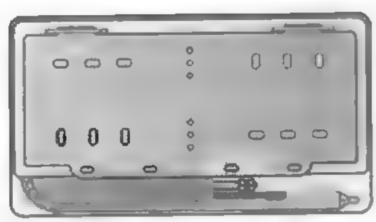
Now the pipework outlet points on the unit must be chosen.

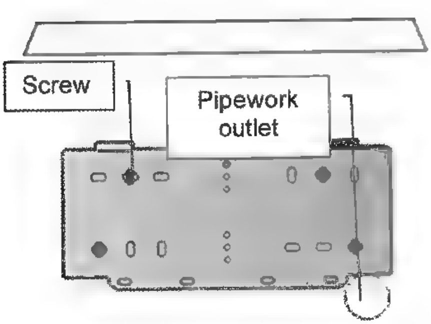


There are six possibilities: two at the sides, two at the bottom, and two at the rear of the unit. The final choice must allow the external connections to be made on the outside of the wall. If there is a leak, these connections must be easily accessible.

The tubing is soft enough to allow it to be bent by hand, but care must be taken to avoid flattening or crushing the tubing.

The wall mounting plate is found at the rear of the unit. If you've decided upon a rear pipework exit, then before drilling out the pipework access through the wall, ensure that the hole will be hidden by the interior unit, but not obstructed by the mounting plate.



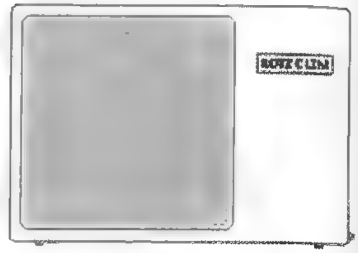



Once the hole is drilled through the wall, you can fix the mounting plate to the wall. Ensure that it is soundly attached to the wall. Use several screws in order to prevent any vibration.

If you ever have to remove the unit to cure unwanted vibration, then omitting screws won't have saved you much time!

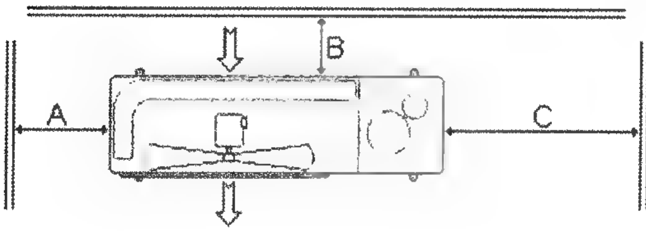
*Now let's look at the installation of the external unit…*

## Installation of the external unit:



Let's take the example of the external unit alongside. Remember that it houses the compressor and the air- cooled condenser. Correct installation will result in adequate passage of air over the condenser, and the elimination of all sources of vibration.

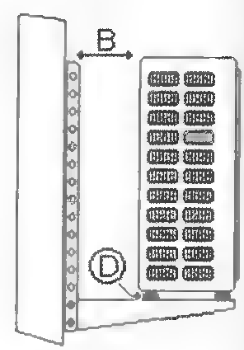
In order to ensure that good air circulation over the condenser does occur, manufacturers specify certain minimum dimensions for location. Distances A and B ensure an adequate supply of air, and leaving a gap C allows easy access to the equipment for routine maintenance. You could be held responsible for any problems caused by failing to follow these guidelines!




The unit can be either fixed to the ground or onto a chassis. In both cases, it should sit on anti- vibration supports (point D) to isolate the various vibrations produced by the unit. Remember that there is oil present in the compressor crankcase, so ensure that the unit is quite level when it is installed.

Whilst on this subject, in storing or transporting external units, don't just put them down in any old position. Always consider the oil, which should always remain in the compressor crankcase. Imagine what the results of a breakdown caused by a compressor without oil would be!

If the equipment is mounted on a chassis, the set-up shown opposite is preferable. The support is hidden behind the unit, which improves its appearance. Always ensure that you leave a gap B.




## Connections:

Once the units are installed, the refrigeration connections, the electrical wiring and the condensate removal pipework must be completed. Observe all guidelines for maximum pipe lengths, and don't exceed the height differences specified by the manufacturer. (See p 198 and subsequent pages).

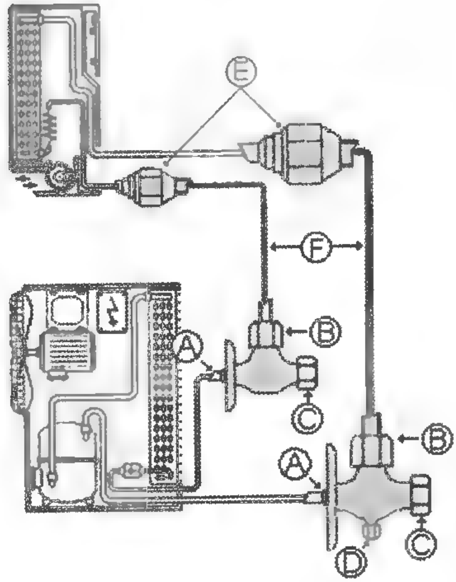
It is better to fit any supports for connections, (e.g. cable glands and conduits) and then concentrate on the refrigeration pipework connection first.

In this way, if there is a need to pull a vacuum on the pipework (when, for example, the equipment uses flare fittings), then this can be underway whilst the wiring and condensate drainage is being completed. You'll save time, and the evacuation will be better.

## Using service valves:

If the unit is fitted with pre- charged pipework, with 'quick' connections, there is no handling of refrigerant necessary. All that is needed is to follow the procedure described on page 193.

Where the air conditioning system is equipped with flare fittings, the pipework is easier to complete, but some operations involving the refrigeration circuit will be necessary.

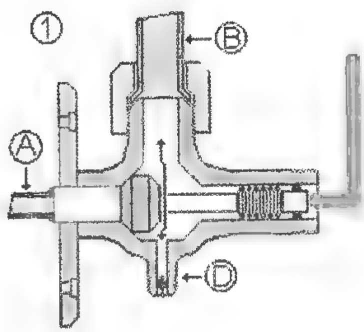



The external unit, which has been pre- charged with refrigerant, is equipped at the factory with two service valves (points A). The internal unit contains nitrogen, and two connections (points E) have been brazed onto its two pipes.

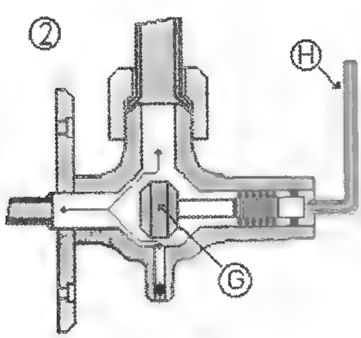
The installer has to complete the pipework (points F) linking B to E. The smaller diameter tubing will take liquid to the expansion device, whilst the large tubing will carry the gas emerging from the evaporator to the suction side of the compressor.

The suction side valve is always supplied with a pressure fitting (D). This is not always so for the liquid valve. Operation of both valves is performed by turning a spindle. This is covered by a cap (points C), to ensure that it is gas- tight.

Let's examine how these service valves operate.



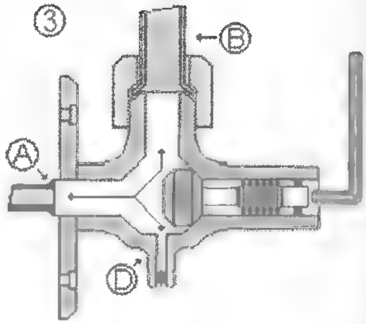

*In position 1:* we say that the valve is front seated (fully closed). The valve plug G closes off the connection with A, which completely isolates the internal unit. On the other hand, the refrigeration pipework (B) and the pressure fitting (D) are connected. ***This is the position of the valve when the unit is supplied.***



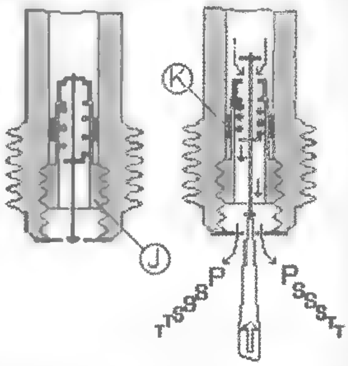

*In position 2: The* valve is in an intermediate position. The internal unit (connected to A), the refrigeration pipework (B) and the pressure fitting are all interconnected.

The valve plug (G) is operated from the exterior using an Allen key (H), which is not supplied.

*In position 3:* The valve is back seated (fully open). The three sides of the plug (A, B, and D) are now fully connected. This is the normal position during operation. The diameter of the orifice between A and B is therefore at a maximum, and the pressure drop across the valve at a minimum. A half-opened valve would produce a large resistance to flow in the refrigeration circuit, and so would be the cause of a breakdown!



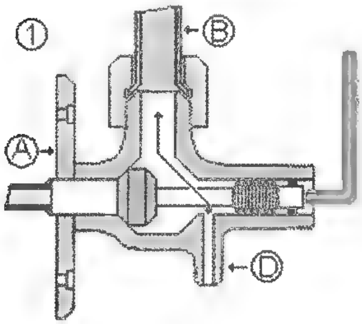

You will notice that it is not possible to isolate the pressure fitting (D) in order to connect a gauge, without losing refrigerant. This is why this fitting is equipped with a "Schraeder" type valve (see J) similar to those fitted to inner tubes. If the stem is under external pressure, the internal spring is compressed and the small valve seat rises, and the valve opens.




Should you ever need to perform a brazing operation close to a fitting of this type, the valve must be dismantled beforehand (using a special tool). Otherwise heat damage to the seal (K) could cause a serious leak!

After use, always replace the protective cap (see D on the previous page) on a pressure fitting to ensure that it is fully gas- tight.

***Note: There is another design of valve where the gauge fitting isn't equipped with a Schraeder valve. In comparison with the valve discussed above, <u>the pressure fitting location is shifted to the right.</u>***

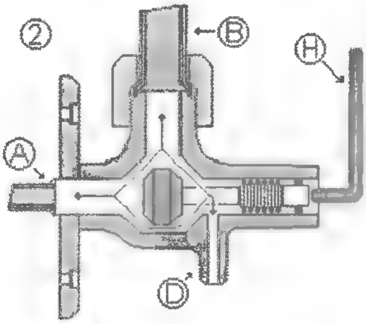


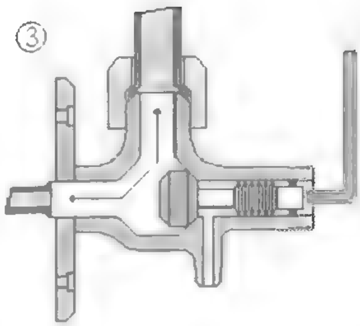

*Position 1:* the valve is fully closed with the plug isolating the internal unit (A).

In this position, the connecting pipework (B) and the pressure fitting (D) are connected. **This is the valve position of the valve when the units are delivered.**

*Position 2:* The valve is in an intermediate position.

The external unit (towards A), the connecting refrigeration pipework (towards B) and the pressure fitting (towards D) are therefore all connected.






*Position 3:* The valve is back- seated (fully open). The external unit is connected to the connecting pipework. *The pressure fitting is completely isolated from the circuit.*

**Note: If you remove the cap from the gauge pressure fitting when the valve is not fully closed, refrigerant will escape to atmosphere.**

*When connecting a gauge, you must:*

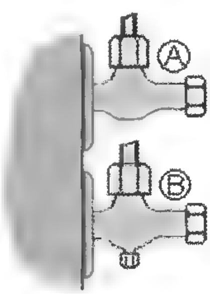
- Check that the valve is fully back-seated (open).
- Unscrew the cover of the gauge fitting, taking care not to lose the gas tight seal which is fitted inside it.
- Connect the flexible hose of the gauge to the fitting.
- Turn the valve to an intermediate position (a ¼ turn should be enough)

*To remove a gauge, you must:*

- Fully Back-Seat the valve.
- Remove the gauge.
- Replace the Cover with its seal
- Check the pressure fitting for leaks.

***When you have to use a service valve, and are not certain that the gauge fitting is equipped with a Schraeder valve, always take the precaution of fully back-seating the valve.***

## Operations on the refrigeration circuit:




Once the refrigeration connections between the two units have been completed, all that remains is to open the valves. How do we proceed if we want to avoid problems?

The smaller tube leads to A, the liquid valve. Observe that there is no pressure connection present. The larger tube leads to B, and this is therefore the vapour valve, which is fitted with a pressure connection and a Schraeder valve. (remember, if there is no Schraeder valve, the pressure fitting will be displaced to the right).

As we saw on page 197, the internal unit is delivered charged with nitrogen (which escapes during the completion of the connections), and the external unit is delivered pre- charged with refrigerant. As for the refrigeration pipework lengths that you've just connected, they are full of atmospheric air.

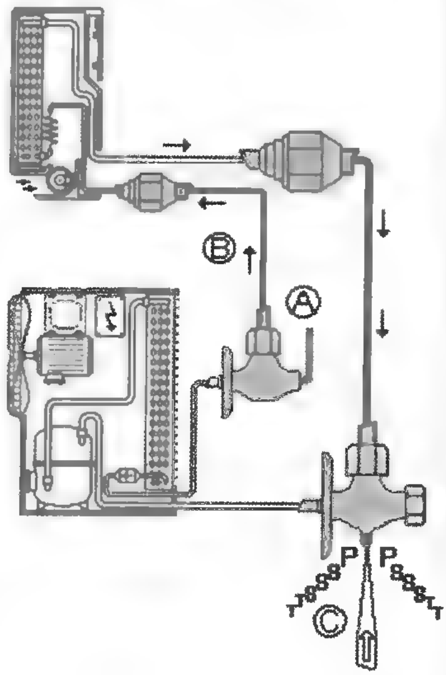
*If you open the valves now, the refrigerant will mix with the air and with any residual nitrogen…*

These mixtures of air and nitrogen (not to mention the moisture contained in the air) will rapidly become the cause of significant problems:

- The moisture results in the creation of acids harmful to the motor windings, which could cause a premature "burnout".
- Air and nitrogen are two gases known as 'non- condensable', 'non-absorbable gases', or 'inerts'. (in fact, they will condense at about –200°C, a temperature that the system will never reach). We'll look at the disastrous consequences of high levels of non- condensables in the system later on.

***Of course it is essential to remove air and nitrogen from the system BEFORE opening the service valves on the external unit!***

## Purging air from the system using the flushing method:




In the past, some installation engineers would use the following method to flush out the air and the nitrogen:

By slightly opening (from ¼ to ½ a turn) the liquid valve (A), the pressurised refrigerant can escape from the external unit and rise inside the liquid pipework, pushing the air contained in the tubing in front of it (B).

If the Schraeder valve at C is now depressed, the air contained in the refrigerant line can escape, forced out by the high pressure of the refrigerant.

After 5 to 10 seconds of purging, refrigerant will reach C having caused the non- condensables to be flushed out in front of it.

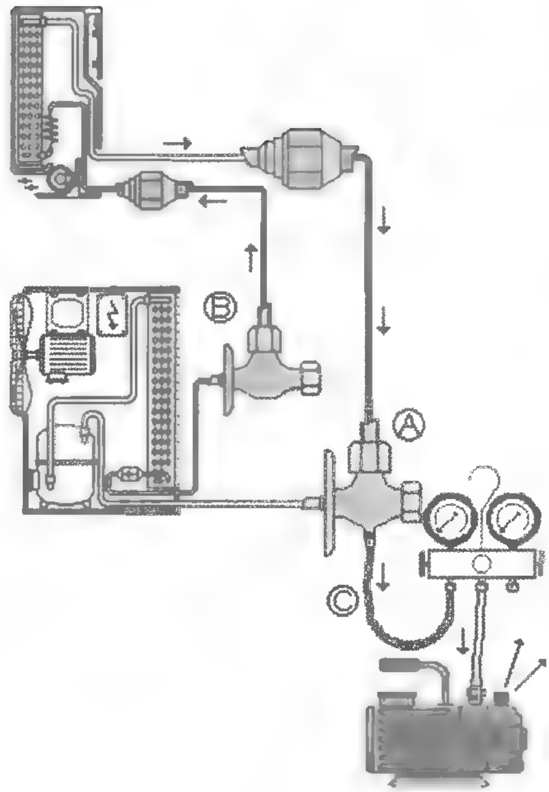
If this purging time is too short, there will still be air or nitrogen remaining in the system. If it is too prolonged, there is the risk of losing refrigerant to the atmosphere, and insufficient refrigerant to allow the unit to operate correctly might be left in the circuit. We will then experience faults due to a lack of charge in the system, which we'll study a little later on.

Note that, depending on the country involved, operations involving refrigerants may be controlled (see page 190). The purging of non–condensables using this method IS NOT NOW A RECOMMENDED PROCEDURE.

We'll now look at how a QUALIFIED AND COMPETENT PROFESSIONAL ENGINEER should proceed in this situation.

## Evacuating a system:

Pulling a vacuum on a system simply involves drawing out all the air and nitrogen contained in the pipework and in the internal unit using a vacuum pump.



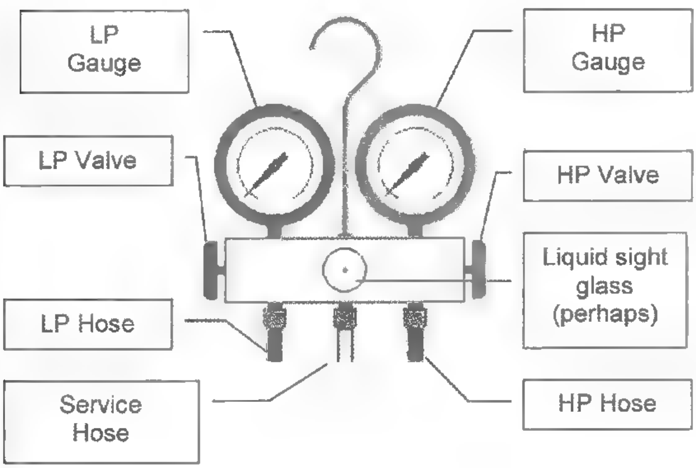

***Since the two service valves are in the fully shut position (the position they were in on delivery of the equipment); the external unit is entirely isolated.***

The pump will remove all the air in the system right back to the liquid valve (ref. B), in the direction of the arrows.

Note that the pressure between valve B and the flexible hose C rapidly falls to well below atmospheric pressure. This reduction in pressure greatly assists the evaporation of any trace of liquid water that may be found in the pipework or inside the internal unit (remember the pressure- temperature relationship for water studied on page 36).

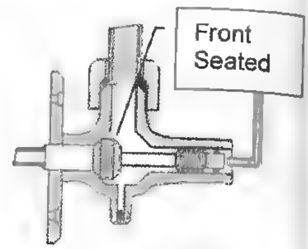
The connection between the vacuum pump and the system is made by means of a gauge set, also known as a manifold.

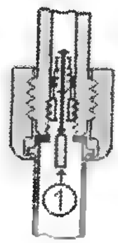
An example of this item is shown below. Note that there may not be a liquid sight glass fitted to all manifolds:




When a system is being evacuated, the manifold valves should be adjusted so that there is a connection between the LP Hose and the service hose, which is attached to the vacuum pump.

➢ **Check that the service valves are in the front seated position:** This is the position they were in when the unit was delivered. These valves stop the refrigerant from leaving the external unit, and *they should never be opened until all other installations have been completed.*



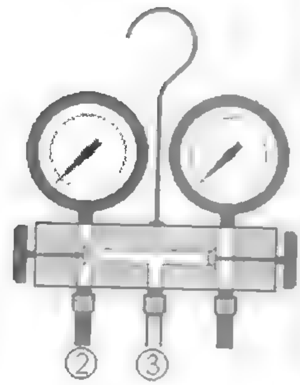

➢ **Connect the LP hose to the pressure fitting on the vapour valve** after making sure that the hose is fitted with a valve depression pin. (Ref. 1). If your hose isn't fitted with a valve depression pin, then you won't be able to evacuate the system.

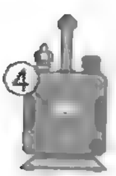
Don't expect to solve this last problem by dismantling the valve. The Schraeder fitting is there to seal the system, and if it's removed, then the refrigerant charge will escape when the hose is disconnected.

➢ **Close the HP valve and open the LP valve on the manifold.**

The manifold valve allows a connection to be made between the LP, HP and Service hoses. In the position shown alongside, the LP valve is open, and there is a connection between the LP (point 2) hose and the service hose (point 3). The HP valve is closed.

Observe that the gauges always show the pressure that exists inside the relevant hose, whatever position the manifold valves are in.




➢ **The pressure readings on the gauges should be equal to atmospheric pressure (i.e. 0 bar) at this point,** or you risk damage to the vacuum pump. It is strongly recommended that you regularly check the level of the oil in the pump using the sight glass (point 4).

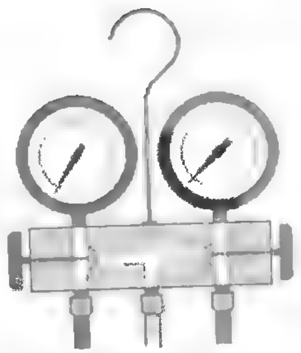
➢ **At this point, you can connect the service hose** to the vacuum pump and start the pump.

➢ **Check that the LP pressure has started to drop** below atmospheric pressure (it should only take a few seconds). If it hasn't, check the manifold valve position, the depression pin on the vapour valve hose, and all threaded connections (there could be a significant leak).

➢ **Allow the system to evacuate** whilst you connect the condensate drainage tube and complete the electrical connection. The longer the system is evacuated, the less likely water is to be left in the system.

Once you've completed the wiring and connection of the condensate drainage tube, you can move onto the next stage...

➢ **Close the manifold LP valve** in order to isolate the vacuum pump, and then stop the pump.



***Make sure that the valve is closed before stopping the pump, otherwise air will get back into the system, and you'll have achieved nothing!***

➢ **Take a reading of the LP pressure** in order to detect any leaks. If the system isn't gas tight, air will get in and the pressure will slowly start to rise.

➢ **Check the electrical connections.** Before powering up the system, it's always better to make one last check. Anyone can overlook something first time around!

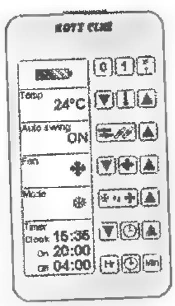
➢ **Check the condensate drainage connection.** This allows a bit of time to check the gas- tightness of the system. If there is a leak, the LP needle will rise slowly towards 0 bar.

➢ **Check if the LP has risen.** If it has, then unfortunately you will have to find the leak, remedy it and the start the evacuation all over again.

➢ **Turn the service valves to the back seated position** starting with the liquid valve and then wait a few minutes for the HP and LP pressures to equalise. (If the pressures are equalised, then this minimises the mechanical strain on the compressor at start- up. This prevents the motor cutting out due to its internal safety device).

➢ **Start up the Air- conditioning system**. Take care before you press the start button that you are absolutely sure that all the manufacturer's guidelines have been followed. If you don't you'll risk both a breakdown and losing your guarantee.

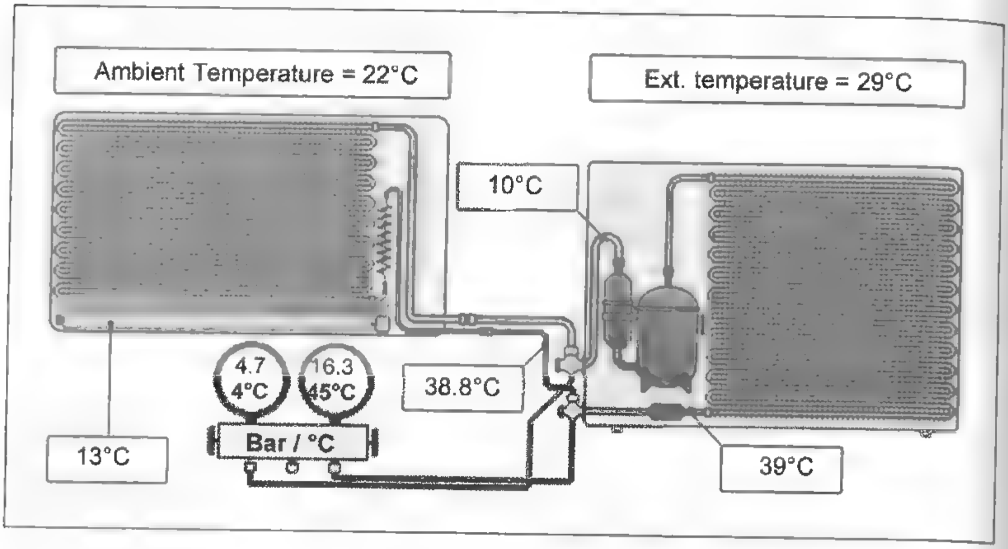
➢ **Check the operating conditions.** Commissioning an installation shouldn't just mean pressing the start button. It's essential that you perform the tests needed to verify that every function of the system is operating exactly as it should.




*Air- conditioning equipment is often fitted with short cycle cut out which prevents the compressor being re-started within six minutes of it cutting out. This isn't a breakdown, therefore, but a feature of normal operation.*

Next you should check the operating conditions, as far as this is possible, by taking pressure and temperature readings. It's by examining equipment that is operating correctly that you will learn to recognise equipment that's operating badly...

Depending on the equipment, and the external conditions, you could get readings like those following:



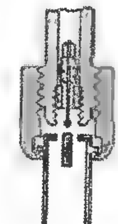

**Internal Unit Side:** ambient temperature = 22°C.
Evaporation temperature = 4°C ⇔ ΔT total = 18°C.
Suction side Temperature = 10°C ⇔ SH[1] = 6°C
Air outflow Temperature = 13°C ⇔ Δt outflow = 9°C.

**External Unit Side:** External Temperature = 29°C.
Condensation Temperature = 45 °C ⇔ ΔT total = 16°C.
Drier inlet liquid temperature = 39°C ⇔ SC[1] = 6°C.
Liquid valve outlet Temperature = 38.8 °C ⇔ No flash-gas.

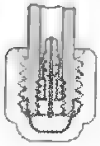
[1] ***SH** is the abbreviation for superheat, and **SC** is the abbreviation for sub-cooling.*

*Interpretation of ΔT at the evaporator was studied on page 156 and at the condenser on page 135: this A/C system is functioning exactly as it should.*

- **Disconnect the LP hose from the pressure fitting.** If it has a Schraeder valve then this should be performed carefully to avoid losing refrigerant.



Start by unscrewing the coupling whilst pressing the hose onto the seal. This ensures that it stays gas- tight whilst being unscrewed. When the coupling has been unscrewed far enough, release the hose.



Always replace the cap on the pressure fitting, making sure that the internal seal is in place.

With the compressor running, check once more that all connections are gas- tight (and indeed, all other parts of the refrigeration circuit that you've worked on).

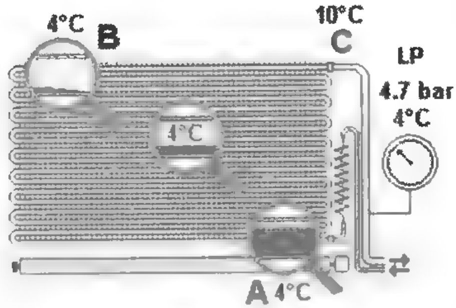
**Every time that you work on a circuit, make a habit of checking for leaks,** especially around the service valves and pressure fittings.

# SYMPTOMS OF MALFUNCTION IN A SYSTEM

## *SUPERHEAT.*

You'll recall that the superheat represents the difference between the evaporation temperature (shown on the LP gauge) and that of the vapour measured at the evaporator outlet.

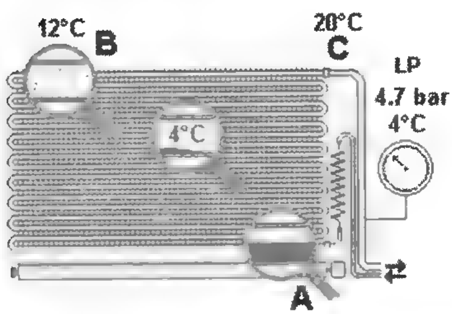
**In normal operation,** what emerges from the expansion device (point A) is a mixture of about 20% vapour and 80% liquid. As it gradually moves through the evaporator, the liquid vaporises by absorbing heat from the air blown over the evaporator by the fan.




The last droplets of vapour evaporate somewhere near the outlet of the evaporator (point B). The vapour then continues being heated until it reaches point C. The superheat is the temperature difference between C and B. In our example, it is equal to 10 - 4 = 6°C, which is quite normal.

### *Excessive Superheat (more that 10 °C).*

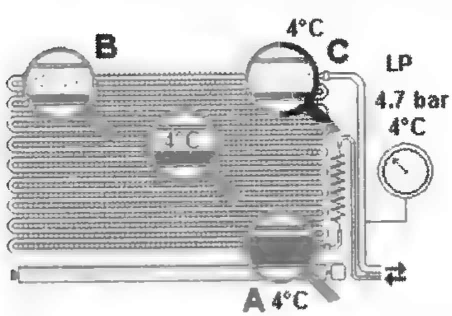
In this next example, with the LP at 4°C, we see a temperature of 20°C at the evaporator outlet, which means a superheat of 20 - 4 = 16°C, which is abnormally high.




Look closely at the diagram alongside. A high superheat indicates that the last droplets of liquid are evaporating much too soon, and so there must be insufficient liquid entering the evaporator.

### *Insufficient Superheat (less than 5°C).*

In this example, with the LP temperature at 4°C, we measure 4°C at the evaporator outlet, that is, a superheat of 0°C. This indicates that there is liquid present at the evaporator outlet. This is dangerous for the compressor, as destructive liquid "slugging" could result.



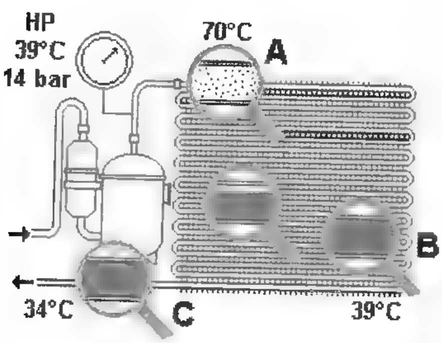

A small superheat means that the evaporator is being supplied with much more liquid than it is capable of evaporating.

**In summary, then, the superheat value enables you estimate the amount of liquid in the evaporator: too large a value means a lack of liquid. Too small a value indicates that the evaporator contains more liquid than it is capable of evaporating.**

## *SUB-COOLING.*

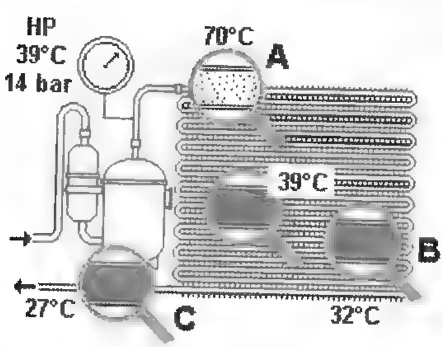
Let's remind ourselves that sub-cooling represents the difference between the condensation temperature (as shown on the HP gauge) and that of the liquid at the condenser outlet.

**In normal operation,** vapour at about 70°C enters the condenser (point A). As it gradually moves through the condenser, it loses its superheat, and then it condenses at a constant temperature and pressure.




At point B, the last molecule of refrigerant vapour condenses. There is then 100% liquid present, which continues to cool until it reaches point C. Sub-cooling is the difference in temperature between B and C. In this example it is equal to 39 - 34 = 5°C, which is quite normal.

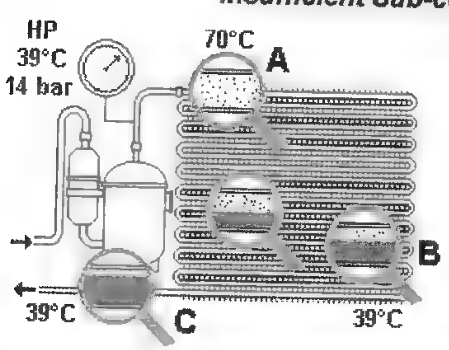
### *Excessive Subcooling (greater than 7°C).*




In this next example, with a HP temperature of 39°C, we obtain a reading of 27°C at the condenser outlet, which gives an excessive sub-cooling of 39 - 27 = 12°C.

Look closely at the diagram shown alongside. A large sub-cooling means that there is much too much liquid in the condenser.

### *Insufficient Sub-cooling (less than 4°C).*




As well as a HP temperature reading of 39°C, we also obtain a reading of 39°C at the condenser outlet. That is, there is an abnormally low sub-cooling of 39 - 39 = 0°C.

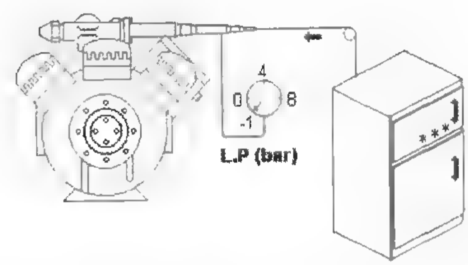
Look closely at the diagram; a small sub-cooling indicates that there is a lack of liquid in the condenser.

**In summary, sub-cooling values allow you to estimate the amount of liquid in the condenser. If it's *too large*, then there is excessive liquid. *Too small* and there is insufficient liquid.**

## *LOW PRESSURE (LP).*

*In simple terms*, the evaporator and the compressor of an A/C system are chosen in the following way. First of all the cooling capacity that is required from the evaporator is calculated (for example 5 kW). Then an evaporator is chosen that is capable of absorbing 5 kW of heat under the required operating conditions. The thermodynamic tables of the various refrigerants available are then used to determine the mass flow of refrigerant needed to absorb this 5 kW (about 100 kg $hr^{-1}$ if R22 is used). From this, the volume of vapour that the evaporator will produce by evaporating this 100kg of R22 is obtained (let's say about 4 $m^3\ hr^{-1}$). Finally a compressor is chosen that will handle 4 $m^3\ hr^{-1}$ of R22 at the anticipated LP and HP pressures (for example 17 bar and 5 bar).

*When the installation is operating, the 4 $m^3\ hr^{-1}$ of R22 vapour produced by the evaporator as it absorbs the 5kW of heat will all be drawn into the compressor, producing an LP Pressure of 5 bar.* If, for any reason, the evaporator produces less than 4 $m^3\ hr^{-1}$ vapour, then since the compressor is capable of handling more vapour than the evaporator can produce, **the LP pressure will fall.**




To help us understand this more easily, imagine the LP that would result from connecting a huge compressor to a household fridge!

**A low LP reading indicates that the compressor can handle more vapour than the evaporator can produce. An elevated LP means that the compressor can't handle enough vapour.**

*Before we perform a review of commonly experienced faults, it is essential that we properly understand the contents of this chapter.*

***The superheat allows us to assess the amount of refrigerant in the evaporator, just as if you could see into the pipework. In the same way, sub-cooling values allow you to "see" the level of liquid in the condenser. The LP values help us assess the ability of the compressor to handle the vapour produced from evaporation of liquid in the evaporator.***

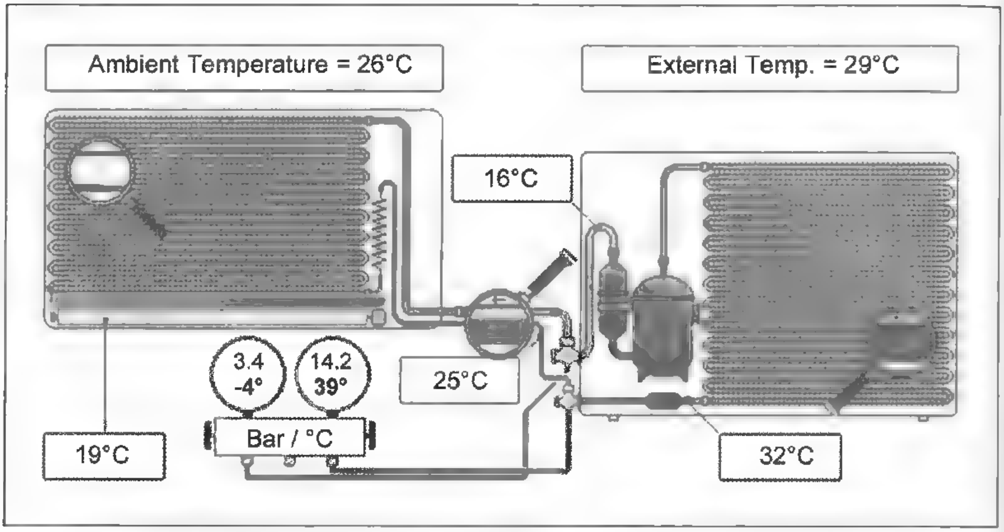
***You should also note that all faults that result in a low LP are referred to as "LP faults", and that conversely, all those causing high HP values are referred to as "HP faults".***

# PRE-EXPANSION FAULTS

## Analysis of this fault:

In order that we can analyse the symptoms of this LP fault (that is, where the LP is too low) let's assume that the installation engineer has only *partly opened* the liquid valve, instead of ensuring that it was fully opened.

You'll see from the table below the measurements made and the values that should be obtained if there wasn't a fault. Try to analyse the symptoms on your own before you read their explanations.




| | Normal Operation *(page 159)* | Values Obtained | Conclusion |
|---|---|---|---|
| **LP** | $T_0 = T_{ambient} - \Delta T_{Total}$<br>$T_0 = 26 - 18 \approx 8°C$ | $P_0 = 3.4$ bar<br>$\mathbf{T_0 = -4°C}$ | **LP too low** |
| **HP** | $T_K = T_{external} + \Delta T_{Total}$<br>$T_k = 29 + 16 \approx 45°C$ | $P_K = 14.2$ bar<br>$T_K = 39°C$ | HP slightly low |
| **SH** | $SH = T_{suction} - T_0$<br>$SH \approx 5$ to $10°C$ | $SH = T_{suction} - T_0$<br>$\mathbf{SH = 16 - (-4) = 20°C}$ | **Superheat too large** |
| **SC** | $SC = T_K - T_{liquid}$<br>$SC \approx 4$ to $7°C$ | $SC = T_K - T_{liquid}$<br>$\mathbf{SC = 39 - 32 = 7°C}$ | **Sub-cooling correct** |
| **$\Delta T_{LL}$** | $\Delta T_{LL} < 1°C$ | $\Delta T_{LL} = 32 - 25$<br>$\mathbf{\Delta T_{LL} = 7°C}$ | **abnormal $\Delta T$ in the liquid line** |
| **$\Delta T_{air}$ evaporator** | $\Delta T_{air\ evap} \approx 8$ to $10°C$ at high speed | $\Delta T_{air\ evap} = 26 - 19$<br>$\Delta T_{air\ evap} = 7°C$ | $\Delta T$ of air at evaporator low |
| **Cond. Clean?** | YES | YES | Condenser is clean |

***The conclusions in grey highlight are characteristics of this fault.***

# Flash-gas: an explanation of the symptoms.

**Abnormal ΔT in the liquid line.** Since the liquid valve is partially closed, its resistance to the flow of refrigerant is excessively high. It acts, therefore, as a kind of *mini expansion device* and causes a drop in pressure and also causes some of the liquid to vaporise. This is why we see this *large difference* (7°C in this example) between the liquid temperature at the condenser outlet temperature, and that measured at the outlet of the valve.

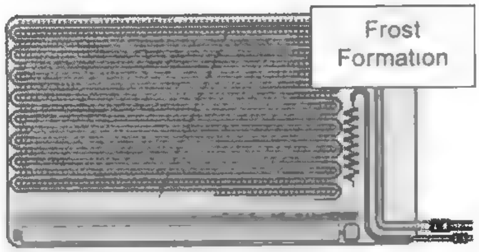
**Lack of Cooling Capacity.** The refrigerant reaches the expansion device already partly vaporised, and at a pressure that is much too low. The flow of refrigerant through the capillary rapidly decreases, therefore, and the evaporator is supplied with insufficient liquid. This is why the refrigerating capacity is reduced. The air- conditioning works poorly, the temperature in the room rises and the client calls you out to repair it.

**Excessive Superheat.** As there is only very little liquid in the evaporator, the last drops of liquid evaporate too quickly. The vapour is in the evaporator for longer in contact with the warm air, so the superheat increases (see page 215).

**LP too low.** The compressor tries to draw in a quantity of vapour greater than that being produced by the evaporator. This is why the LP drops sharply, as does the evaporation temperature (see page 217).

**Good sub-cooling.** As the condenser is receiving less heat to eject, it has excess capacity. The refrigerant is therefore cooled more and the condensation pressure drops. In addition, since there is less refrigerant in the evaporator, there must be more in the bottom of the condenser, and there is good sub-cooling (see page 216).

**Remarks**: In a normally operating air- conditioning system, the evaporation temperature is always slightly above 0°C. Since flash-gas means that the LP drops, the evaporation temperature falls below zero, and the condensate that runs down the evaporator fins has a tendency to freeze.



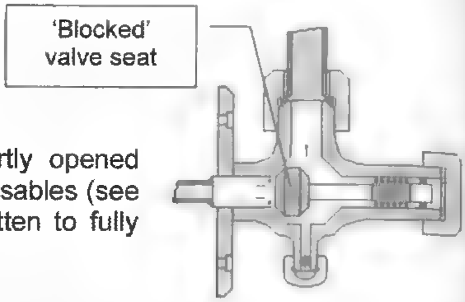

As the frost is an excellent thermal insulator, the exchange of heat between the refrigerant and the air is reduced. This frost could spread over the evaporator, and even completely cover it. You'd then have two faults occurring at the same time: flash-gas and lack of evaporating capacity (which will be studied on page 228). **So let the evaporator defrost before you start any fault diagnosis.**

**A low LP *(an LP fault)*,**
**an excessive superheat,**
**a correct sub-cooling value**
**and an abnormal temperature difference across the liquid line**

**are characteristic symptoms of flash-gas.**

## Faults producing flash-gas: some examples.

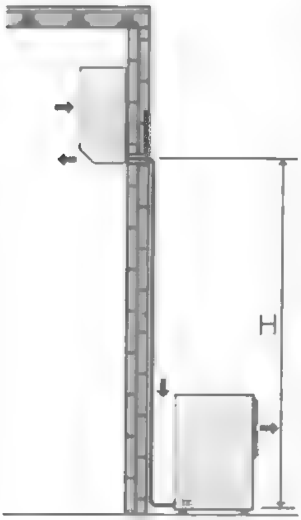
**The liquid valve is 'blocked'**




This fault is caused by an error made during the commissioning of the equipment.

The installation engineer has partly opened the liquid valve to 'chase' out non-condensables (see page 210), and has subsequently forgotten to fully open (back- seat) the valve.

**The max. height difference has been exceeded.**




We've already seen this fault which arises from a failure to observe the manufacturer's recommendations (pages 200 and 201).

If the evaporator is situated above the condenser set, the pressure of the liquid gradually falls as it rises in the liquid line pipework. If the pressure falls below the value of the pressure temperature relationship that corresponds to the liquid temperature, then flash-gas will occur.

To avoid this sort of misadventure, the maximum height indicated on the installation instructions must be scrupulously observed. If installation constraints mean that you have to exceed this height, then contact the manufacturer for a solution to this problem that will not nullify your guarantee.

**The liquid line passes through a very warm location:**

If there is a possibility that the liquid line will become excessively hot (from direct sunlight, proximity to a heat source etc.), then it must be insulated. If the liquid temperature becomes excessively high, flash-gas may be produced.

**The filter-drier is blocked:**

In a comfort air- conditioning system, this type of problem occurs only infrequently, due to the factory conditions in which the equipment was assembled. Where connections are made on- site care must be take to prevent the ingress of copper swarf (from be- burring of tubing), brazing debris or abrasive powder.

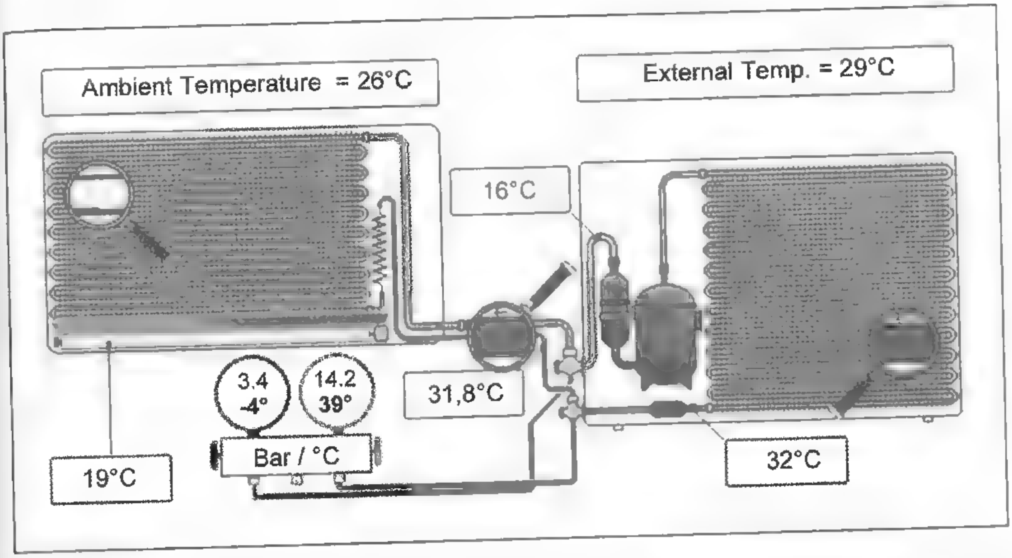
This fault is easily detected by the characteristic temperature difference that will be observed between the filter inlet and outlet.

# LACK OF EXPANSION DEVICE CAPACITY

## Analysis of the fault:

To analyse the symptoms of this LP fault (LP excessively low) we will assume that the capillary expansion device is *partially blocked* by some sort of contamination.

As for the previous fault, you will find below different measurements made, and the values that should be obtained if there were no faults. Try and analyse the symptoms yourself before reading the explanation of the symptoms that follows.




| | Normal operation *(page 159)* | Values obtained | Conclusion |
|---|---|---|---|
| **LP** | $T_0 = T_{ambient} - \Delta T_{Total}$ <br> $T_0 = 26 - 18 \approx 8°C$ | $P_0 = 3.4$ bar <br> $\mathbf{T_0 = -4°C}$ | **LP too low** |
| **HP** | $T_K = T_{external} + \Delta T_{Total}$ <br> $T_k = 29 + 16 \approx 45°C$ | $P_K = 14.2$ bar <br> $T_K = 39°C$ | HP slightly low |
| **SH** | $SH = T_{suction} - T_0$ <br> $SH \approx 5$ to $10°C$ | $SH = T_{suction} - T_0$ <br> $\mathbf{SH = 16 - (-4) = 20°C}$ | **Superheat too large** |
| **SC** | $SC = T_K - T_{liquid}$ <br> $SC \approx 4$ to $7°C$ | $SC = T_K - T_{liquid}$ <br> $\mathbf{SC = 39 - 32 = 7°C}$ | **Sub-cooling correct** |
| **$\Delta T_{LL}$** | $\Delta T_{LL} < 1°C$ | $\Delta T_{LL} = 32 - 31.8$ <br> $\mathbf{\Delta T_{LL} = 0.2°C}$ | **No Abnormal ΔT across the liquid line** |
| **$\Delta T_{air}$ evaporator** | $\Delta T_{air\ evap} \approx 8$ to $10°C$ at high speed | $\Delta T_{air\ evap} = 26 - 19$ <br> $\Delta T_{air\ evap} = 7°C$ | ΔT of the air across the evaporator low |
| **Cond. Clean?** | YES | YES | Condenser is clean |

***The conclusions in grey highlight are characteristics of this fault.***

## Lack of expansion device capacity: explanation of symptoms.

**Lack of refrigerating capacity**. An obstruction of the capillary tube results in a large increase in its resistance to the flow of refrigerant, which decreases sharply. The evaporator is therefore poorly supplied with refrigerant, and the cooling capacity diminishes. Since cooling of the room being air- conditioned is poor, the ambient temperature rises, and the client calls you out on a breakdown.

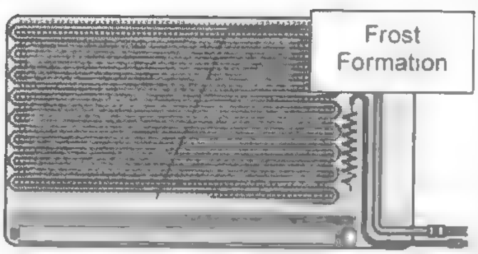
**Excessive superheat.** As there is only very little liquid in the evaporator, the last drops of liquid evaporate too quickly. The vapour is in the evaporator for longer in contact with the warm air, so the superheat increases (see page 215).

**LP too low.** The compressor tries to draw in a quantity of vapour greater than that being produced by the evaporator. This is why the LP drops sharply, as does the evaporation temperature (see page 217).

**Good sub-cooling.** As the condenser is receiving less heat to eject, it has excess capacity. The refrigerant is therefore cooled more and the condensation pressure drops. In addition, since there is less refrigerant in the evaporator, there must be more in the bottom of the condenser, and there is good sub-cooling (see page 216).

**No abnormal ΔT along the liquid line.** The symptoms of a lack of expansion device capacity are almost identical to those of flash-gas. *The only difference between the two faults is the ΔT values measured along the liquid line.* Take care not to confuse these faults (flash-gas has been discussed on page 218).

**Remarks:** In a normally operating air- conditioning system, the evaporation temperature is always slightly above 0°C. Since a lack of expansion valve capacity means that the LP drops, the evaporation temperature falls below zero, and the condensate that runs down the evaporator fins has a tendency to freeze.




As the frost is an excellent thermal insulator, the exchange of heat between the refrigerant and the air is reduced. This frost could spread over the evaporator, and even completely cover it. You'd then have two faults occurring at the same time: a lack of expansion device capacity and a lack of evaporating capacity (which will be studied on page 228). **So let the evaporator defrost before you start any fault diagnosis.**

**A low LP *(an LP fault)*,**
**an excessive superheat,**
**a good sub-cooling**
**and <u>no abnormal temperature difference</u> along the liquid line**

**are the characteristic symptoms of a lack of expansion device capacity.**

## Lack of expansion device capacity: some examples.

**The capillary tube is partially blocked:**

This is the most likely cause of problems with a capillary. Its internal cross section is so small, that even the slightest amount of impurity (copper swarf, particles of abrasive, brazing debris etc.) could block it. To protect the expansion device, manufacturers install upstream filter-driers.

If it is possible to fit two gauges (LP and HP) then you can confirm your diagnosis by stopping the compressor. The pressures should quickly equalise. If the capillary is fully blocked, then equalisation of the pressures after stopping the compressor will not occur. If there is partial obstruction, the larger the obstruction is then the longer it takes for equalisation to occur. The capillary must then be replaced (see page 144).

**The capillary tube is partially crushed:**

The capillary could be partially flattened from a number of causes. This rather rare fault, by reducing the internal cross section, normally produces symptoms of the last fault.

**The capillary tube has the wrong dimensions:**

The quantity of liquid that passes through a capillary depends on the difference between the LP and HP pressures, but also on its length and its internal diameter (see page 141). If a genuine replacement part supplied by the manufacturer of the defective equipment, and corresponding exactly to the damaged capillary in all respects is used, then replacement is relatively simple to perform.

On the other hand, if you try to fabricate a replacement capillary yourself, this will probably be the starting point for any number of problems. Always order the correct spare instead!

Generally speaking, the manufacturer is unlikely to have made an error in specification or in assembly. On the other hand, ordering the wrong spare is easily done and much more common. Always read the equipment reference numbers very carefully!

**Remarks:**

Manufacture of a capillary expansion device is a delicate operation that takes into account different operating conditions, the type of refrigerant used, the cooling capacity required etc.

Using an air conditioning unit in conditions not foreseen by the manufacturer seriously reduces its operational lifetime. For example, to use equipment where the ambient temperature is too low, or where the external temperature is excessively high could result in liquid slugging and so destroy the compressor in a short time.

This is why it's essential to stay within the operating condition limits set by the manufacturer.

## The HP is too low:

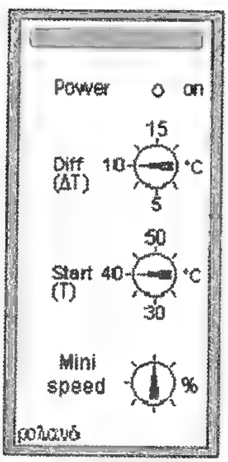
On occasion it is necessary to air condition an area even when the weather is cold (computer rooms, laboratories etc.). In these instances, since the external temperature is low, the condensation pressure will be low.

Since the HP has decreased, the flow of refrigerant passing through the capillary will similarly decrease (see page 143). When this occurs, the capillary expansion device shows all the symptoms of a lack of expansion device capacity.

To avoid this fault, a piece of equipment called an "all seasons kit" must be fitted. This allows a reasonable HP pressure to be maintained even in the presence of low external temperatures.

Nowadays, the commonest technique used in comfort A/C involves modifying the flow of air over the condenser according to the condensing temperature:

- If the HP increases, the fan runs at full speed and the condenser produces its maximum cooling capacity.
- If the HP falls, the fan speed is reduced, which reduces the capacity of the condenser, and limits the drop in HP.




The probe for this type of controller is usually fitted on an end piece (crosspiece), and somewhere towards the middle of the condenser.

On most of these controllers you'll find:

- A "Start" control feature that allows the user to set the temperature at which the condenser fan should start running.
- A " Diff " control that allows the user to set the temperature difference that must occur for nominal fan speed (100%) to be used.
- A " Mini speed " control which enables the minimum fan speed to be set (below a certain speed, the fan motor could stall)

In our example, the fan starts running at its lowest speed at a condensation temperature of 40°C, and it reaches its maximum speed at 40 + 10 = 50°C.

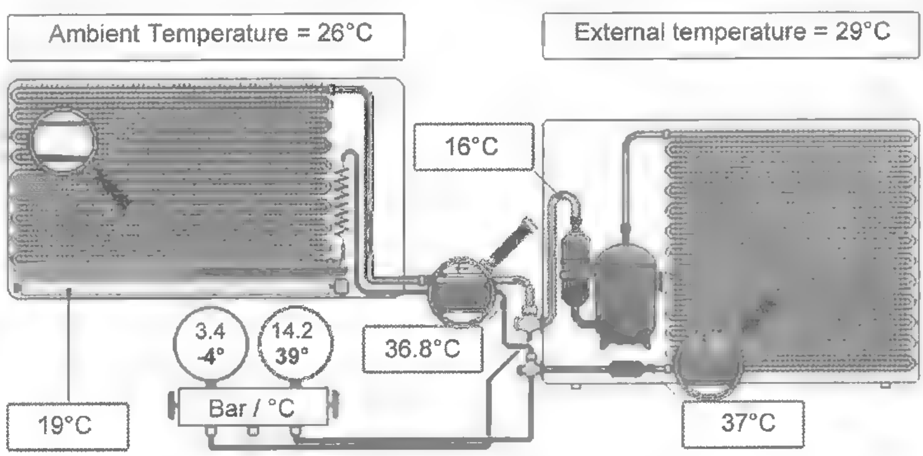
Wiring diagrams and operating instructions are supplied with the kit.

# LACK OF REFRIGERANT

## Analysis of the fault:

In order to analyse the symptoms of this LP fault (LP too low), we'll assume that there is a leak at one of the connections, and so there is a lack of refrigerant.

As for the previous fault, you will find below different measurements made, and the values that should be obtained if there were no faults. Try and analyse the symptoms yourself before reading the explanation of the symptoms that follows.




| | Normal Operation *(page 159)* | Values obtained | Conclusion |
|---|---|---|---|
| **LP** | $T_0 = T_{ambient} - \Delta T_{Total}$<br>$T_0 = 26 - 18 \approx 8°C$ | $P_0 = 3.4$ bar<br>**$T_0 = -4°C$** | **LP too low** |
| **HP** | $T_K = T_{external} + \Delta T_{Total}$<br>$T_k = 29 + 16 \approx 45°C$ | $P_K = 14.2$ bar<br>$T_K = 39°C$ | HP slightly low |
| **SH** | $SH = T_{suction} - T_0$<br>$SH \approx 5$ to10°C | $SH = T_{suction} - T_0$<br>**$SH = 16 - (-4) = 20°C$** | **Superheat too large** |
| **SC** | $SC = T_K - T_{liquid}$<br>$SC \approx 4$ to 7°C | $SC = T_K - T_{liquid}$<br>**$SC = 39 - 37 = 2°C$** | **Sub-cooling too small** |
| **$\Delta T_{LL}$** | $\Delta T_{LL} < 1°C$ | $\Delta T_{LL} = 37 - 36.8$<br>$\Delta T_{LL} = 0.2°C$ | **No Abnormal ΔT across the liquid line** |
| **$\Delta T_{air\ evaporator}$** | $\Delta T_{air\ evap} \approx 8$ to 10°C at high speed | $\Delta T_{air\ evap} = 26 - 19$<br>$\Delta T_{air\ evap} = 7°C$ | ΔT of the air across the evaporator low |
| **Cond. Clean?** | YES | YES | Condenser is clean |

***The conclusions in grey highlight are characteristics of this fault***

## Lack of refrigerant: explanation of the symptoms.

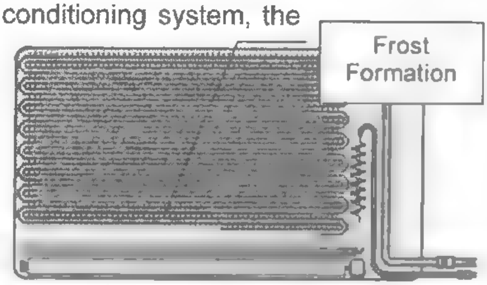
**Lack of refrigerating capacity.** If there is a lack of refrigerant in the system as a whole, then this lack is critical in the evaporator. This is the reason for the loss of refrigerating capacity. Since cooling of the room being air- conditioned is poor, the ambient temperature rises, and the client calls you out on a breakdown.

**Excessive superheat.** As there is only very little liquid in the evaporator, the last drops of liquid evaporate too quickly. The vapour is in the evaporator for longer in contact with the warm air, so the superheat increases (see page 215).

**LP too low.** The compressor tries to draw in a quantity of vapour greater than that being produced by the evaporator. This is why the LP drops sharply, as does the evaporation temperature (see page 217).

**Sub-cooling too small.** Since the condenser is being supplied with less heat to dissipate, it has excessive capacity. The refrigerant is cooled to a larger extent, and the condensing pressure falls. However, the lack of liquid at the bottom of the condenser means that there is very little sub-cooling, or even none at all if there is a serious lack of refrigerant (see page 216). There is therefore a high risk that flash-gas will be produced (see page 199).

**Remark:** In a normally operating air- conditioning system, the evaporation temperature is always slightly above 0°C.




Since a lack of refrigerant means that the LP drops, the evaporation temperature falls below zero, and the condensate that runs down the evaporator fins has a tendency to freeze.

As the frost is an excellent thermal insulator, the exchange of heat between the refrigerant and the air is reduced. This frost could spread over the evaporator, and even completely cover it. You'd then have two faults occurring at the same time: a lack of refrigerant and lack of evaporating capacity (which will be studied on page 228). **So let the evaporator defrost before you start any fault diagnosis**

**A low LP *(an LP fault)*,**
**An excessive superheat**
**And small sub-cooling**

**Are the characteristic symptoms of a lack of refrigerant.**

*Note that a competent engineer would never add refrigerant to a system before establishing that the sub-cooling is too small, and before finding and repairing any leaks.*

## Lack of refrigerant: some practical considerations.

**Leaks:**

A lack of refrigerant (or 'lack of charge') is often due to a failure to ensure that a system is gas-tight. Leaks are often found at connections and at service valves. The following statement can never be stressed too strongly: leak checking is indispensable, and must always be rigorously performed when work is carried out on a refrigeration circuit.

If you're using an electronic leak detector that you may have had for some time, check it's specifications to ensure that it can, in fact, detect the refrigerant in use in the system. Some older detectors designed for R12 / R22 / R502, say, do not respond to some of the newer refrigerants (e.g. R134a / R404A / R407C/R410A).

There are detergent solutions available that are especially formulated for the detection of leaks. All you do is apply some of the solution to any suspect points in the system (connections, brazed areas etc.) and check that no bubbles are formed. In an emergency, you could even use a solution of liquid detergent and water (such as 'Teepol') applied to connections with a brush.

Finally, remember that refrigerant leaving the compressor transports the oil that it carries throughout the system. This is why the locations where there are leaks are generally oily, so simply passing your hands over pipework and connections will often identify possible leaks.

**Charging a system:**

Charging a system fitted with a capillary expansion device isn't easy without the correct equipment. If the charge is too small, the A/C unit will lack cooling capacity, and the compressor will overheat. If the charge is too great, there is a continual risk that the compressor will be subjected to destructive liquid 'slugging'.

In the context of this introductory manual, we should simply restrict ourselves to saying that charging a system rapidly and safely requires the use of a balance or set of scales (or a charging cylinder, although this is less common nowadays). It is essential to ensure that the exact quantity of the correct refrigerant is used in the equipment, as indicated on the identification plate. (If the equipment already contains refrigerant, see page 190).

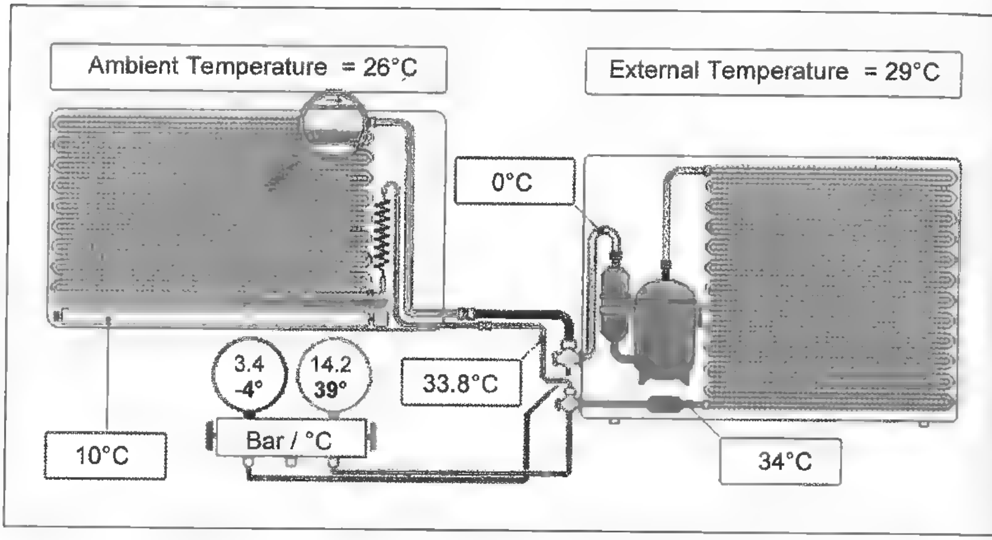
***Problems associated with leaks and with charging systems are discussed in more detail in the REFREPAIR MANUAL (by the same author, pages 67 to 71, and pages 317 to 320). The problems raised by the use of newer refrigerants are explained in that manual (pages 405 to 417), as is the recovery of refrigerant (pages 391 to 404).***

# LACK OF EVAPORATOR CAPACITY

## Analysis of the fault:

In order to analyse the symptoms of this LP fault (LP is low), we'll assume that *the filters at the evaporator inlet are blocked.*

Once more, you'll see below the values obtained from measurements made if there were no faults. Try and analyse the symptoms yourself before going on to read the explanations.




| | normal operation *(page 159)* | Values obtained | Conclusion |
|---|---|---|---|
| **LP** | $T_0 = T_{ambient} - \Delta T_{Total}$<br>$T_0 = 26 - 18 \approx 8°C$ | $P_0 = 3.4$ bar<br>$\mathbf{T_0 = -4°C}$ | **LP too low** |
| **HP** | $T_K = T_{external} + \Delta T_{Total}$<br>$T_k = 29 + 16 \approx 45°C$ | $P_K = 14.2$ bar<br>$T_K = 39°C$ | HP slightly low |
| **SH** | $SH = T_{suction} - T_0$<br>$SH \approx 5$ to $10°C$ | $SH = T_{suction} - T_0$<br>$\mathbf{SH = 0 - (-4) = 4°C}$ | **Superheat too small** |
| **SC** | $SC = T_K - T_{liquid}$<br>$SC \approx 4$ to $7°C$ | $SC = T_K - T_{liquid}$<br>$SC = 39 - 34 = 5°C$ | Good Sub-cooling |
| $\mathbf{\Delta T_{LL}}$ | $\Delta T_{LL} < 1°C$ | $\Delta T_{LL} = 34 - 33.8$<br>$\Delta T_{LL} = 0.2°C$ | No abnormal $\Delta T$ across the liquid line |
| $\mathbf{\Delta T_{air}}$ **evaporator** | $\Delta T_{air\ evap} \approx 8$ to $10°C$ at high speed | $\Delta T_{air\ evap} = 26 - 10$<br>$\mathbf{\Delta T_{air\ evap} = 16°C}$ | **See Next page** |
| **Cond. clean** | YES | YES | Condenser is Clean |

***The conclusions in grey highlight are characteristics of this fault***

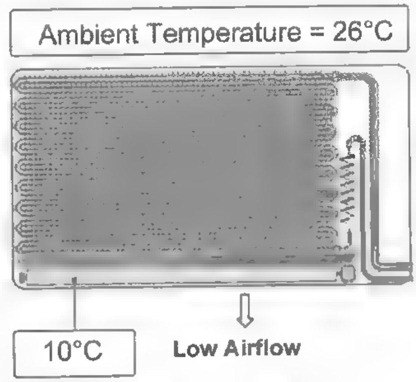
## Lack of Evaporator Capacity: Two families of faults:

Two types of anomalies can cause a lack of evaporator capacity: A lack of airflow, and a 'fouled' evaporator.

### Lack of airflow:

If airflow is low, the velocity of the air passing over the evaporator is reduced. The air therefore stays longer in contact with an evaporator whose temperature is much lower than normal.

As a result, the air becomes excessively cold, and the outflow temperature drops. At the same time, since the refrigeration capacity is reduced, the ambient temperature rises. This is why the temperature difference between the air inlet and outlet becomes abnormally large.

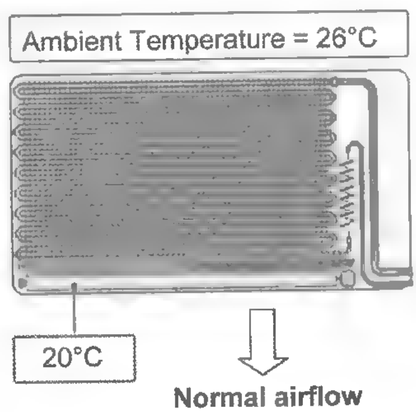



**A lack of airflow over the evaporator causes an increased temperature difference between the air inlet and outlet.**

### A 'fouled' Evaporator:

If the loss of capacity is due to fouling or clogging of the fins and pipework of the evaporator, the heat exchange between the refrigerant and the air is very much reduced, as the 'debris' covering the evaporator acts as a thermal insulator.

As a result, the air passing over the evaporator is insufficiently cooled, and the outflow temperature increases. This is why the temperature difference between the air inlet and outlet decreases.




**If the evaporator is fouled, there is a decreased temperature difference between the air inlet and outlet.**

**This ΔT value for the air differentiates the two families of faults due to insufficient evaporator capacity. *At high speed* a large ΔT indicates a low airflow whilst a smaller ΔT indicates a fouled evaporator.**

## Lack of Evaporator Capacity: explanation of the symptoms.

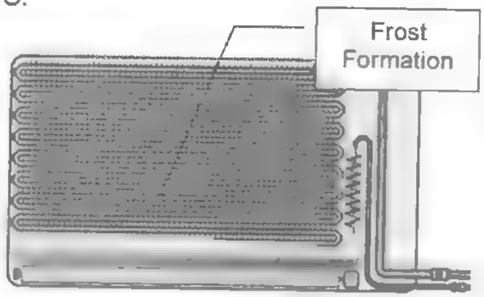
**Lack of Cooling Capacity**. Whether it's due to a lack of airflow, or a fouled evaporator, the refrigerating capacity will decrease. As the room will not be cooled effectively, the ambient temperature will rise, and your client will call you out for a breakdown.

**Superheat too small.** Because of the poor heat exchange between the refrigerant and the air, the liquid refrigerant absorbs less heat, so it evaporates more slowly and travels further towards the evaporator outlet. This is why the superheat decreases (see page 215). In extreme circumstances, liquid 'slugging' could even occur and damage the compressor, and the inlet pipework could frost up completely.

**LP too low.** The compressor tries to draw in a quantity of vapour greater than that being produced by the evaporator. This is why the LP drops sharply, as does the evaporation temperature (see page 217).

**ΔT of the air at the evaporator.** *At high speed,* a large ΔT indicates a lack of airflow, whilst a somewhat smaller ΔT indicates a fouled evaporator. In order to choose between the two hypothetical faults, it is generally sufficient to inspect the state of the filters, and perhaps even clean them!

**Remark**: In a normally operating air- conditioning system, the evaporation temperature is always slightly above 0°C.




Since lack of evaporator capacity means that the LP drops, the evaporation temperature falls below zero, and the condensate that runs down the evaporator fins has a tendency to freeze.

As the frost is an excellent thermal insulator, the exchange of heat between the refrigerant and the air is reduced. This frost could spread over the evaporator, and even completely cover it. There would then be a significant risk of compressor damage due to liquid 'slugging' or even frosting right up to the suction side of the compressor.

***Whenever frosting or icing up occurs, always stop the compressor and allow the evaporator to defrost before any further diagnosis.***

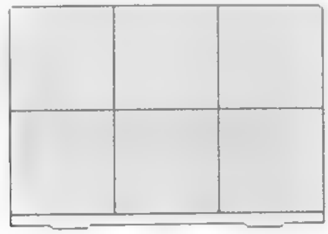
**A low LP (an LP fault)**
**and a fairly small superheat**

**Are characteristics of a lack of evaporator capacity.**

*All LP faults cause increased superheat unless there is a lack of evaporator capacity. This makes it particularly easy to diagnose.*

## Lack of evaporator capacity: some examples

**Filters are dirty:**



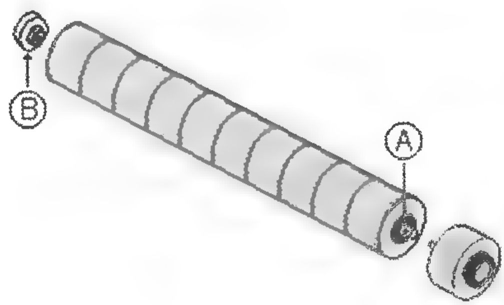
In comfort A/C, the filters are designed to trap the various impurities contained in the air. These impurities eventually cause the filter to become blocked. Always ensure that these filters are cleaned regularly, especially as the majority of filters fitted to this type of equipment are washable.

**Pipework and fins are fouled:**

This problem can be more critical as it can sometimes necessitate changing the evaporator. This fault occurs principally in systems which are badly maintained, and are operating with damaged filters (or sometimes even without any filters at all).

However, there are other locations where the risks of this occurring are high, for example hairdressing salons. In these areas, the filters cannot trap the vapours from lacquer, which are then deposited on the fins and pipework of the evaporator, forming an insulating layer. Another example is those areas used by "heavy smokers". Nicotine and tar vapours easily pass through the filters, and then condense on the evaporator. There they form a yellow film, which is just as good an insulator as hair lacquer. Night-clubs are good places for this!

**Slipping fans**




Tangential fans are fitted to their motor shafts by means of a small grub screw (fig. A). If this screw becomes loose, the fan slips, its' speed of rotation falls and the airflow drops sharply.

Sometimes the fan turbine moves and comes loose from its mounting (fig B) during transport. On start-up, the fan is stuck, and doesn't turn. It is strongly recommended that the free rotation of the fan be checked by hand before applying current to the motor.

**Re-circulation:**

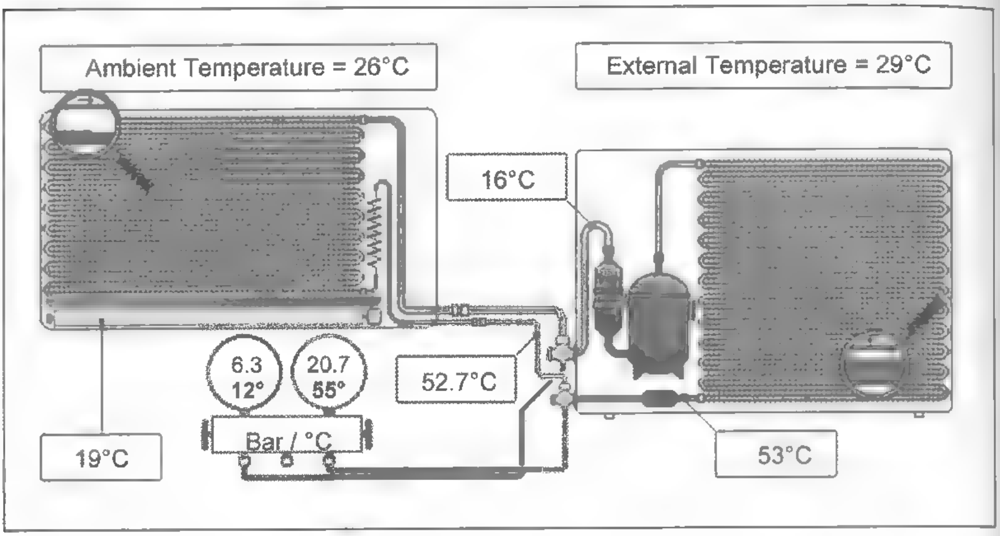
Attention should always be paid to the direction of the flow of cold air blown from the evaporator. It should always produce the required comfortable conditions without ever being directed over the occupants of an area. Also, attention should be paid to any possible 're-circulation'. If some of the air comes up against an obstacle, it might be drawn into the air intake once again. When this happens, the average air temperature at the evaporator intake falls, therefore the evaporation temperature also falls (remember that it depends on $\Delta T_{Total}$). If the temperature for the LP pressure falls below 0°C, the evaporator will start to frost- up!

# LACK OF CONDENSER CAPACITY

## Analysis of the fault:

In order to analyse the symptoms of this HP fault (HP high), we'll assume that the condenser is fouled.

Just as with the LP faults we've studied up until now, you'll see below the values obtained from measurements made, as well as those expected if there were no faults. Try and analyse the symptoms yourself before going on to read the explanations.




| | Normal operation *(page 159)* | Values obtained | Conclusion |
|---|---|---|---|
| **LP** | $T_0 = T_{ambient} - \Delta T_{Total}$<br>$T_0 = 26 - 18 \approx 8°C$ | $P_0 = 6.3$ bar<br>**$T_0 = 12°C$** | **LP high** |
| **HP** | $T_K = T_{external} + \Delta T_{Total}$<br>$T_k = 29 + 16 \approx 45°C$ | $P_K = 20.7$ bar<br>**$T_K = 55°C$** | **HP too high** |
| **SH** | $SH = T_{inlet} - T_0$<br>$SH \approx 5$ to 10°C | $SH = T_{inlet} - T_0$<br>$SH = 16 - 12 = 4°C$ | Superheat rather small |
| **SC** | $SC = T_K - T_{liquid}$<br>$SC \approx 4$ to 7°C | $SC = T_K - T_{liquid}$<br>**$SC = 55 - 53 = 2°C$** | **Sub-cooling small** |
| **$\Delta T_{LL}$** | $\Delta T_{LL} < 1°C$ | $\Delta T_{LL} = 53 - 52.7$<br>$\Delta T_{LL} = 0.3°C$ | No abnormal $\Delta T$ on the liquid line. |
| **$\Delta T_{air}$** evaporator | $\Delta T_{air\ evap} \approx 8$ to 10°C at high speed | $\Delta T_{air\ evap} = 26 - 19$<br>$\Delta T_{air\ evap} = 7°C$ | $\Delta T$ small for air over evaporator |
| **Cond. Clean ?** | YES | **NO** | **Condenser fouled** |

***The conclusions in grey highlight are characteristics of this fault***

## Lack of Condenser Capacity: two families of faults.

Lack of condenser capacity can be caused by two types of different anomalies: lack of airflow and a fouled condenser.

When trying to chose between these two hypothetical breakdowns, don't attempt to measure the ΔT of the air (as we did with the lack of evaporator capacity, page 229). This is usually of limited use with the axial fans used on external units of comfort A/C systems.

The best course of action is quite simply to visually inspect the state of the condenser (which is straightforward to do) and to clean it if required. If the condenser is clean, and *if the HP remains high with a small sub-cooling*, it suggests a lack of airflow.

## Lack of Condenser Capacity: Explanation of the symptoms.

**HP high.** If the condenser is badly fouled, the heat exchange between the refrigerant and the air is poor. Since the refrigerant is not being effectively cooled, its temperature, and hence its pressure, rises. This is why the HP becomes abnormally high.

**Excessively small sub-cooling.** Since condensation of the refrigerant takes place only with difficulty, the last molecule of vapour condenses late and there is very little liquid in the bottom of the condenser. This is why the subcooling is greatly reduced, and in extreme instances, can even become zero. (see page 216).

**Lack of Cooling Capacity.** Since the HP value is excessively high, the compressor "struggles", and its suction capacity tends to decrease. The mass of refrigerant circulating and hence the refrigeration capacity is reduced as a result.

**Remark:** Since the compressor draws in less vapour, the LP rises (as it does for all HP faults). Because the HP value is high, excessive liquid passes through the capillary, and the superheat tends to get smaller.

As the compressor "labours", it uses more current, and could even cut out on the electrical safety devices ("klixon" or circuit breaker). The area being air-conditioned will cease to be cooled, and the client will call you out on a breakdown.

**A high HP (an HP fault)**
**And small subcooling**

**Are characteristic of a lack of condenser capacity.**

*All HP faults cause a noticeable increase in sub-cooling except for lack of condenser capacity. It is therefore an easy fault to diagnose.*

## Lack of condenser capacity: some examples:

**Pipework and fins are fouled:**

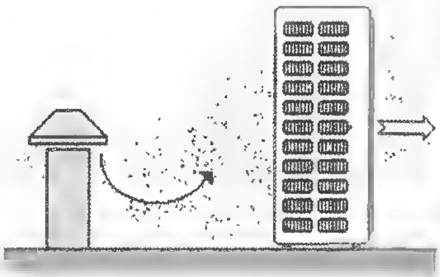
Unlike the evaporator, condensers are not protected by air filters. Generally installed externally, they are swept by air full of dust, smoke, flying insects, etc.

These difficult operating conditions explain the frequency of this fault, which particularly tends to occur when condensers aren't regularly maintained.

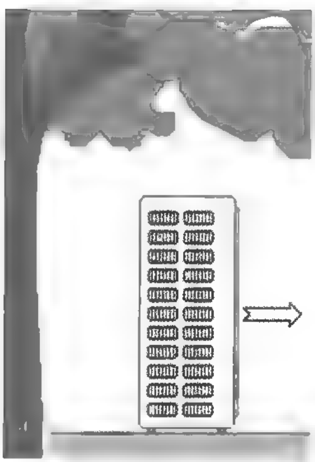
**The location of the condenser has been badly chosen:**

When an air-cooled condenser is being installed, particular attention needs to be paid to its location if unexpected and unwelcome surprises are to be avoided.

For example, when installing a condenser on a roof or terraced area, try to avoid placing it so that it draws in vapour (directly or because of prevailing winds) from any extractor outlets that may be close by. Above all, oily fumes, (such as those from a restaurant kitchen), or hot vapour (from a boiler chimney) should be avoided.



As far as oily fumes are concerned, they collect on all surfaces of pipework and fins of a condenser. Any environmental dust will then stick to the oily surfaces and the fouling process rapidly accelerates.

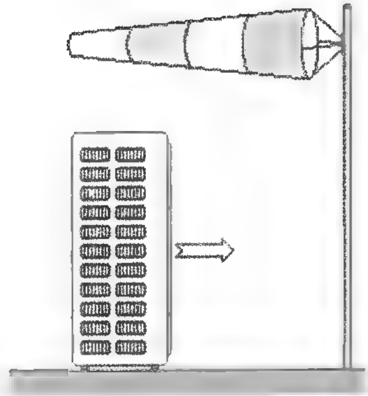


Another example of installations that could cause problems is that of an air-cooled condenser placed close to trees.

When the A/C is in operation between seasons, falling leaves must not be drawn into the condenser in autumn. If they are, they will significantly reduce both the surface area and the airflow. This will result in a large increase in the HP pressure.

When a location is being chosen for a condenser, consideration should always be given also to any regulations (e.g. listed or protected sites) that might apply, any noise nuisance produced by the equipment, prevailing winds, snowfalls, or flooding etc.

**The condenser fan turns in reverse:**



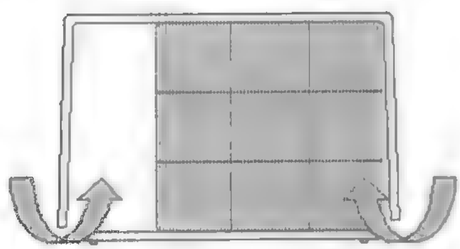
When the external unit is not operating, if a strong gust of wind blows over the fan blades, the fan could start to spin rapidly.

The fans in single-phase split systems have a low starting torque. This means that if the wind is turning the fan rapidly in the wrong direction (as in the sketch alongside) it is possible that this inverse rotation will continue when there is voltage applied to the fan motor. This will result in a reduced airflow and an increased HP.

The starting torque for three-phase motors is generally larger, and when voltage is applied, they cannot rotate in the wrong direction. However, if the wind is causing them to rotate in the wrong direction when they are not running, it is possible that electrical safety devices would cut out when voltage is applied. In addition, wind blowing in the opposite direction can oppose the flow of air across the condenser sufficiently to cause a reduction in airflow. When this happens, the HP increases.

**There is an air inlet between the condenser and the fan:**

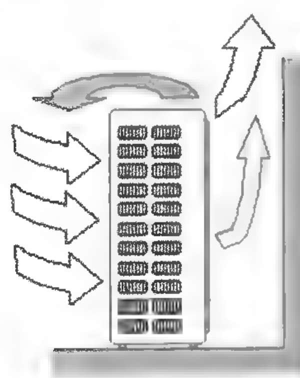
The fan should draw air through the condenser. Occasionally, if the body panels or casing are poorly finished, a significant quantity of air could be drawn directly to the fan, without passing over the condenser.



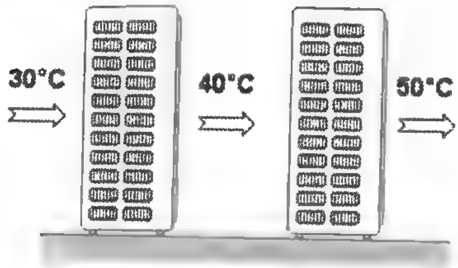
In this instance, the effective reduction in the airflow passing over the condenser could be sufficient to cause an abnormal increase in the HP pressure.

Take care that the external system never operates without the body panels in place, even in trials.

**Hot discharged air is returning to the condenser:**



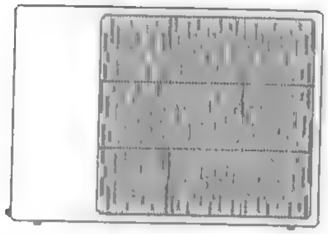
There are many ways in which the unwanted re-circulation of warm air into the fan intake can take place. In the example alongside, the external unit is situated much too close to a wall. A large proportion of the warm air emerging from the condenser manages to rise up the wall and escape quite normally to the atmosphere. At the same time, however, a stream of warm air ricochets against the wall and is drawn once more to the condenser inlet, which is at a slightly reduced pressure. Because of this "accidentally" re-cycled warm air, the average temperature of air entering the condenser is higher than normal, and the HP rises.




Another problem can occur when several external units are installed side by side. In the example opposite, air at 40°C discharged by the first condenser is drawn into the second, whose HP therefore increases.

These re-circulation problems are not always easy to resolve. Always take care, therefore, during installation.

**A large number of fins are fouled:**



Whatever the reasons for this problem, it is one that frequently arises. If the fins are fouled or clogged, there is poor circulation of air, which leads to a reduced airflow, and hence an increased HP.

Avoid cleaning the condenser with a high-pressure power-washer. This has the unfortunate effect of actually blocking the fins.

The blocked areas should be brushed out carefully with one of the battery-powered combs that are available on the market, which closely match the original gaps in between the fins.

**The fan blades slip on their arbour:**

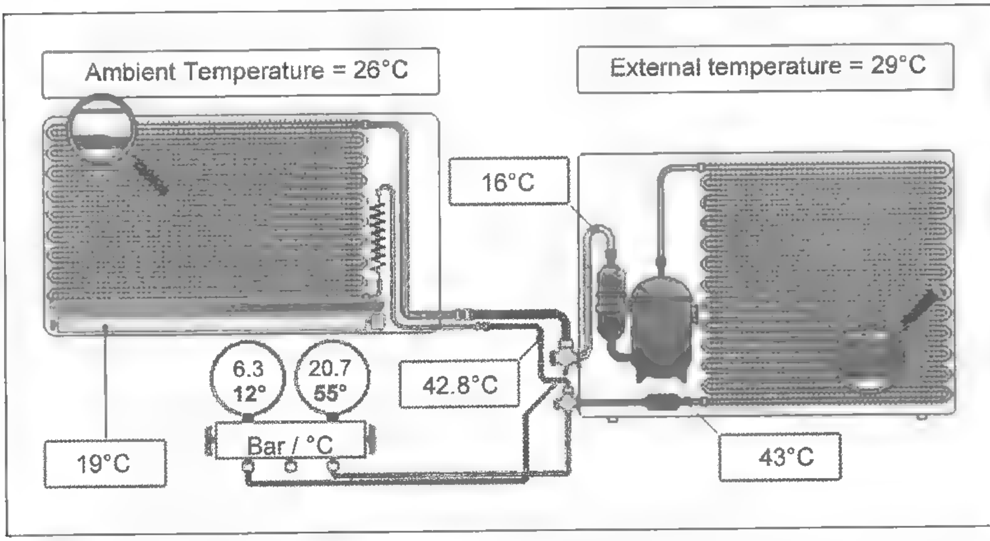
This tends to occur most often with small fans, when location of the fan blades is made by means of single fixing bolt. A quick visual inspection will identify this problem, especially as a warning is often provided in the form of unusual noises caused when the fan propeller "wanders" on the motor arbour.

# EXCESSIVE REFRIGERANT CHARGE

## Analysis of the fault:

In order to help us analyse the symptoms of this fault (high HP), we'll assume that somehow the equipment has accidentally been overcharged with refrigerant.

As usual, you'll find below the measurements taken, and the values you could expect if there were no faults. Try and analyse the symptoms yourself before going on to read their explanations.




| | Normal operation *(page 159)* | Values obtained | Conclusion |
|---|---|---|---|
| **LP** | $T_0 = T_{ambient} - \Delta T_{Total}$<br>$T_0 = 26 - 18 \approx 8°C$ | $P_0 = 6.3$ bar,<br>**$T_0 = 12°C$** | **LP high** |
| **HP** | $T_K = T_{external} + \Delta T_{Total}$<br>$T_k = 29 + 16 \approx 45°C$ | $P_K = 20.7$ bar<br>**$T_K = 55°C$** | **HP very high** |
| **SH** | $SH = T_{inlet} - T_0$<br>$SH \approx 5$ to $10°C$ | $SH = T_{inlet} - T_0$<br>$SH = 16 - 12 = 4°C$ | Superheat quite small |
| **SC** | $SC = T_K - T_{liquid}$<br>$SC \approx 4$ to $7°C$ | $SC = T_K - T_{liquid}$<br>**$SC = 55 - 43 = 12°C$** | **Sub-cooling very large** |
| **$\Delta T_{LL}$** | $\Delta T_{LL} < 1°C$ | $\Delta T_{LL} = 43 - 42.8$<br>$\Delta T_{LL} = 0.2°C$ | No abnormal $\Delta T$ across the liquid line |
| **$\Delta T_{air}$ evaporator** | $\Delta T_{air\ evap} \approx 8$ to $10°C$ at high speed | $\Delta T_{air\ evap} = 26 - 19$<br>$\Delta T_{air\ evap} = 7°C$ | Small $\Delta T$ for air at evaporator |
| **Cond. Clean?** | YES | YES | Condenser is clean |

***The conclusions in grey highlight are characteristics of this fault***

## Excess refrigerant charge: explanation of the symptoms.

**Sub cooling very large.** Since there is a large volume of refrigerant in the system, there is a lot of refrigerant in the bottom of the condenser. This is why the sub cooling is larger than usual (see page 216).

**HP very high.** Since the sub-cooling zone has increased, the remaining surface available for condensation decreases. Therefore, as we've seen (p132) that condensation is responsible for removal of 80% of the heat, the refrigerant is less effectively cooled, and so its temperature and hence its pressure increases. This is why the HP becomes very large.

**Lack of cooling capacity.** The HP increases, the compressor "struggles", and its suction capacity tends to decrease. The volume of refrigerant circulating decreases, as does its refrigerating capacity.

**Remarks:** Since the compressor draws in less vapour, the LP rises (as it does for all HP faults). Because the HP value is high, excessive liquid passes through the capillary, and the superheat tends to get smaller. As the compressor "labours", it uses more current, and could even cut out on the electrical safety devices ("klixon" or circuit breaker). The area being air-conditioned will cease to be cooled, and the client will call you out on a breakdown.

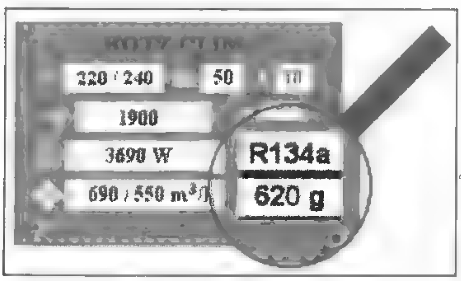
**A very high HP** ***(a HP fault),***
**A large sub-cooling**
***And an absence of non -condensables*** [1]

**Are characteristic of excessive refrigerant charge.**

[1] *Excessive refrigerant charge gives exactly the same symptoms as the presence of non-condensables, which will be studied on the next page. In both cases, see page 241 for the course of action you need to take.*

As a reminder, the type and quantity of refrigerant that should be used in the equipment is always shown on the identification plate.

Charging refrigerant into a system fitted with a capillary expansion device is not a straightforward operation. The type and amount of the refrigerant to be used in the system must be strictly observed. In the example opposite, the equipment must be charged with exactly 620 grams of refrigerant R134a (see page 190).




*This subject is covered in detail in the REFREPAIR MANUAL (by the same author, pages 391 to 404). This 626 page manual, which is dedicated solely to refrigeration and electrical fault-finding and repair will enable you to expand upon the knowledge that you've gained once you've mastered the contents of this manual.*

# NON- CONDENSABLES

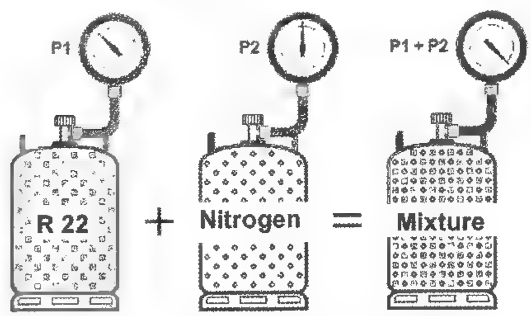
First of all, let's remind ourselves that 'non- condensables' is the term that we use for gases that cannot be condensed at temperatures normally found in a refrigeration circuit. For example, air and nitrogen, which condense at about –200°C are non- condensables.

**What effects do non- condensables have?**

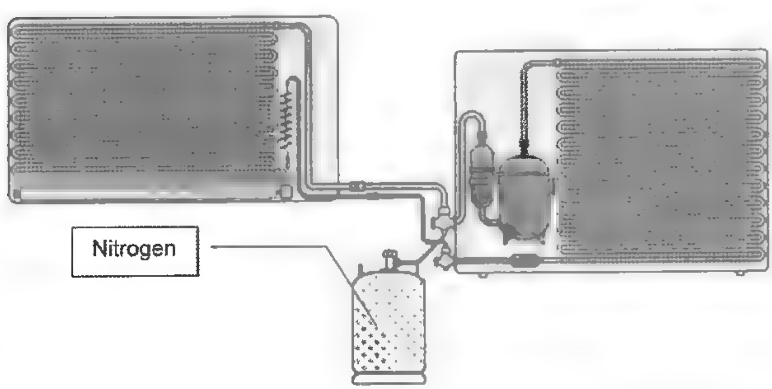
Remember what *Dalton's Law* states: The total pressure of a mixture of gases is equal to the sum of their partial pressures.

*To allow us to understand this better, let's apply it to the set-up shown below.*

- The three cylinders have exactly the same volume.
- Cylinder 1 contains R22 vapour, at pressure P1.
- Cylinder 2 contains nitrogen, at pressure P2.
- If we introduce both gases into cylinder 3 (which is empty), the gauge would show a reading of P3 = P1 + P2.




Now let's apply this law to the refrigeration circuit below:



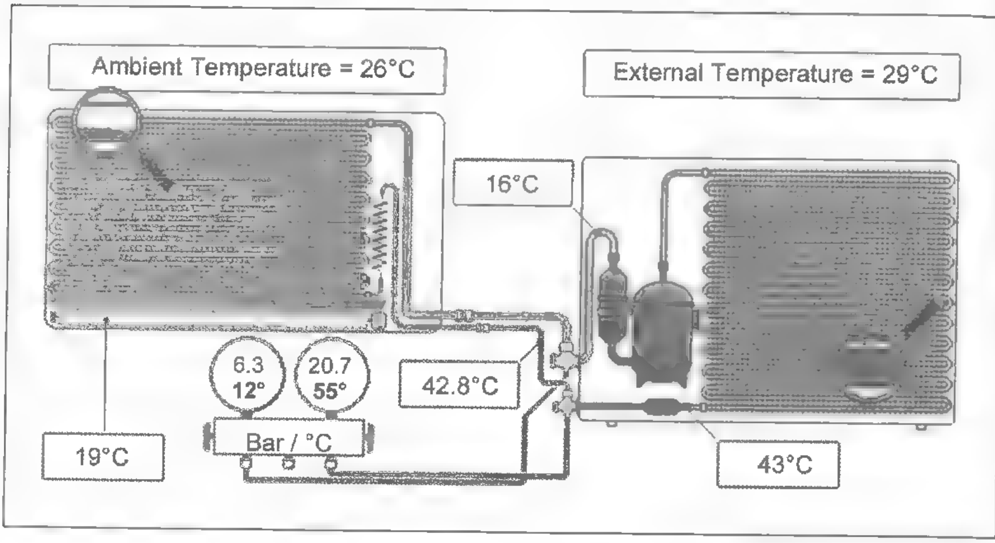

If we add nitrogen to the circuit, the partial pressure will add itself to that of the refrigerant to give a total pressure greater than that expected from the pressure– temperature relationship for the refrigerant. For example, at 20°C, R22 is at 8.2 bar. If there is the equivalent of 2 bar of nitrogen in the system, **the gauge would read 10.2 bar (that is, 24°C) even though the liquid is at 20°C.**

Remember that internal units with flare fittings are delivered under a pressure of nitrogen (see pages 197 and 209). Poor technique could, therefore, easily allow nitrogen or air to be trapped in the system.

## Analysis of the fault:

Let's imagine that the installation engineer of the circuit below had neither a vacuum pump nor knowledge of how to effectively purge the air and nitrogen out of the system (see page 210).

*The system therefore is full of non- condensables.* Try and analyse for yourself the different measurements obtained with this HP fault.




| | Normal operation *(page 159)* | Values obtained | Conclusion |
|---|---|---|---|
| **LP** | $T_0 = T_{ambient} - \Delta T_{Total}$<br>$T_0 = 26 - 18 \approx 8°C$ | $P_0 = 6.3$ bar,<br>$\mathbf{T_0 = 12°C}$ | **LP very high** |
| **HP** | $T_K = T_{external} + \Delta T_{Total}$<br>$T_k = 29 + 16 \approx 45°C$ | $P_K = 20.7$ bar<br>$\mathbf{T_K = 55°C}$ | **HP very high** |
| **SH** | $SH = T_{inlet} - T_0$<br>$SH \approx 5$ to $10°C$ | $SH = T_{inlet} - T_0$<br>$SH = 16 - 12 = 4°C$ | Superheat rather small |
| **SC** | $SC = T_K - T_{liquid}$<br>$SC \approx 4$ to $7°C$ | $SC = T_K - T_{liquid}$<br>$\mathbf{SC = 55 - 43 = 12°C}$ | **Sub-cooling very large** |
| **$\Delta T_{LL}$** | $\Delta T_{LL} < 1°C$ | $\Delta T_{LL} = 43 - 42.8$<br>$\Delta T_{LL} = 0.2°C$ | No abnormal $\Delta T$ across the liquid line |
| **$\Delta T_{air}$ evaporator** | $\Delta T_{air\ evap} \approx 8$ to $10°C$ at high speed | $\Delta T_{air\ evap} = 26 - 19$<br>$\Delta T_{air\ evap} = 7°C$ | $\Delta T$ of the air at evaporator small |
| **Cond. Clean** | YES | YES | Condenser is clean |

***The conclusions in grey highlight are characteristics of this fault***

*If you take a look at the data for excessive refrigerant charge (page 237) you'll observe that both tables are absolutely identical!*

## Non- condensables: explanation of the symptoms.

**Excessive Sub-cooling:** As we saw on page 239, the HP gauge shows a temperature reading much higher than the true reading of the condensation temperature. This is why measurements give a sub-cooling value that appears to be high.

**HP very high.** In accordance with Dalton's Law, the partial pressure of non-condensables adds itself to the pressure of the refrigerant. This is why the gauge reading shows an abnormally high HP.

**Lack of Refrigerating Capacity.** As the HP is increased, the compressor "struggles" and its suction capacity tends to fall. The volume of refrigerant circulating, and hence the cooling capacity, therefore decrease.

**Remark:** As the compressor is drawing in less vapour, the LP increases (as it does with all HP faults). Since the HP has increased, excessive refrigerant passes through the capillary, and the superheat tends to decrease. Since the compressor "labours", it takes a larger current, and it could even cut out due to the electrical security devices ("klixon" or circuit breaker). The area being air-conditioned will no longer be effectively cooled, and the client will call you out on a breakdown.

**A very high HP** ***(a HP fault),***
**A large sub-cooling**
***And the presence of non- condensables*** (1)

**Are characteristic for faults caused by non- condensables.**

*(1) Non- condensables give exactly the same symptoms as excessive refrigerant charge (studied on page 237). The actions to be taken are shown below.*

<u>Practical Aspects.</u> This fault is often a direct consequence of one or more errors of technique in the installation of the equipment. These could include flared pipe-lengths not being properly evacuated before valves are opened, poor handling of the system components, careless charging of the system etc. Generally, in order to differentiate this fault from excessive refrigerant charge, a "non- condensables" test should be performed.

***In practice,*** **for small comfort A/C systems, whether the fault is due to excessive refrigerant charge or the presence of non- condensables,** ***the course of action is the same:*** **all the refrigerant must be removed, then the correct charge of new refrigerant introduced to the system.** ***So don't worry about the test! .***

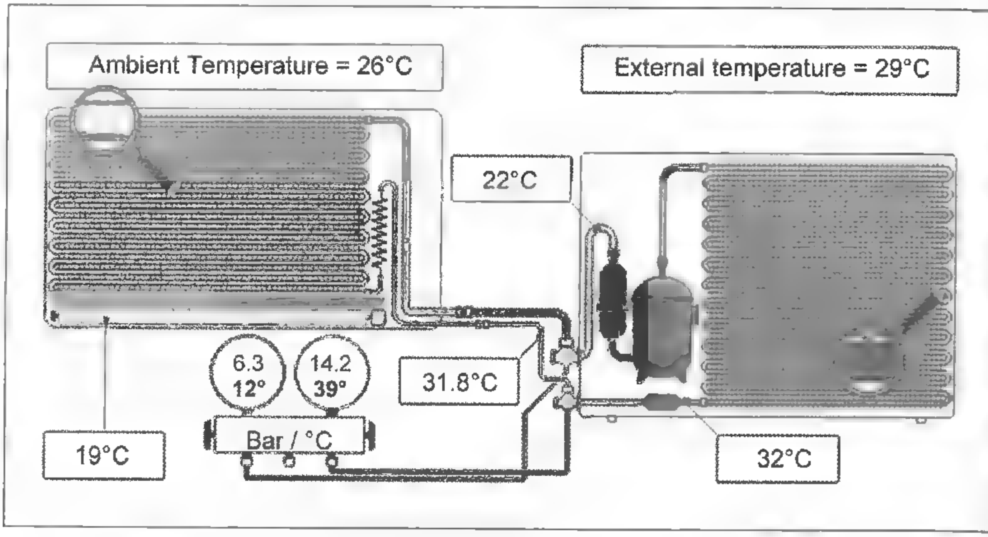
**<u>In both cases you must:</u>**

- Recover all the refrigerant using a recovery set.
- Carry out an Oil Acidity Test if possible.
- Pull a vacuum on the system.
- Recharge the system using a balance or a charging cylinder.
- Complete the operation by performing leak tests and operating tests.

# LACK OF COMPRESSOR CAPACITY

## Analysis of the fault:

A client calls you because his air conditioning isn't getting "cold". You obtain the measurements below: What do they tell you?




| | Normal operation *(page 159)* | Values obtained | Conclusion |
|---|---|---|---|
| **LP** | $T_0 = T_{ambient} - \Delta T_{Total}$<br>$T_0 = 26 - 18 \approx 8°C$ | $P_0$ = 6.3 bar,<br>$\mathbf{T_0 = 12°C}$ | **LP very high** |
| **HP** | $T_K = T_{external} + \Delta T_{Total}$<br>$T_k = 29 + 16 \approx 45°C$ | $P_K$ = 14.2 bar<br>$\mathbf{T_K = 39°C}$ | **HP very low** |
| **SH** | $SH = T_{inlet} - T_0$<br>$SH \approx 5$ to $10°C$ | $SH = T_{inlet} - T_0$<br>$SH = 22 - 12 = 10°C$ | Superheat slightly high |
| **SC** | $SC = T_K - T_{liquid}$<br>$SC \approx 4$ to $7°C$ | $SC = T_K - T_{liquid}$<br>$SC = 39 - 32 = 7°C$ | Sub-cooling correct |
| $\mathbf{\Delta T_{LL}}$ | $\Delta T_{LL} < 1°C$ | $\Delta T_{LL} = 32 - 31.8$<br>$\Delta T_{LL} = 0.2°C$ | No abnormal ΔT across the liquid line |
| $\mathbf{\Delta T_{air}}$ **evaporator** | $\Delta T_{air\ evap} \approx 8$ to $10°C$ at high speed | $\Delta T_{air\ evap} = 26 - 19$<br>$\Delta T_{air\ evap} = 7°C$ | ΔT for air at the evaporator small |
| **Cond. Clean?** | YES | YES | Condenser is clean |

***The conclusions in grey highlight are characteristics of this fault***

*This fault is neither an LP fault (since this is high) nor is it a HP fault (since this is low)* ***This is the only fault that simultaneously gives a low HP and a high LP.***

## Lack of compressor capacity: explanation of the symptoms.

The expression "lack of compressor capacity" indicates that the volume of refrigerant being pumped by the compressor is much too low. For example, liquid hammer could have damaged a valve reed in a piston compressor (p71) or the moving plate in a rotary compressor is not gas-tight (p188).

**Lack of Refrigerating Capacity.** Since the compressor lacks capacity, the volume of refrigerant being circulated in the system is much too low, and the cooling capacity drops sharply. Since the area being air- conditioned is not being effectively cooled, the client calls you out on a breakdown.

**LP very high.** Since the compressor lacks capacity, it draws in less vapour than the evaporator is producing. This is why the LP is abnormally high (see page 217).

**HP very low.** Since the cooling capacity is low, the amount of heat discharged by the condenser falls sharply. It is therefore as if the condenser has excess capacity. The refrigerant is excessively cooled, and the condensation temperature, and hence the HP, falls.

**A very low HP *(so this is not a HP fault)***
**And a very high LP (*so this is not an LP fault*)**

**Are characteristic of a lack of compressor capacity.**

**Practical Aspects:** Compressors used in comfort A/C, whatever their design, are all hermetic types, and therefore non- repairable. The only thing to be done is to change the compressor for an identical replacement.

Beforehand, the following checks should be made:

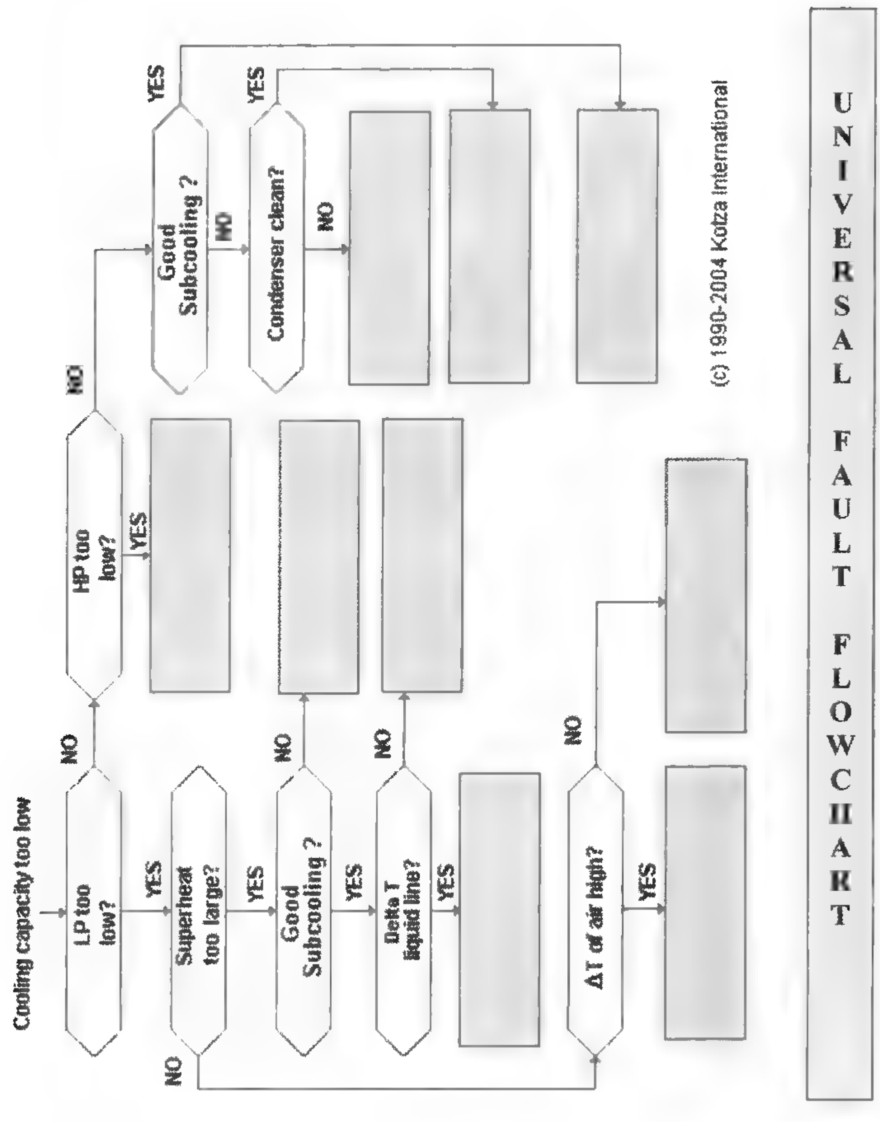
- Check that the compressor motor is operational (the best way is to measure the current it takes). If it isn't working, there is an electrical fault (see: single-phase motors, Page 254).

- If a reversible A/C unit is involved, the compressor may be in perfect working order, but the slide of the four-way valve could be stuck in an intermediate position. In this instance, there is effectively an open connection between the HP and the LP regions, which gives exactly the same symptoms as a lack of compressor capacity (see: the reversible A/C system, p246.)

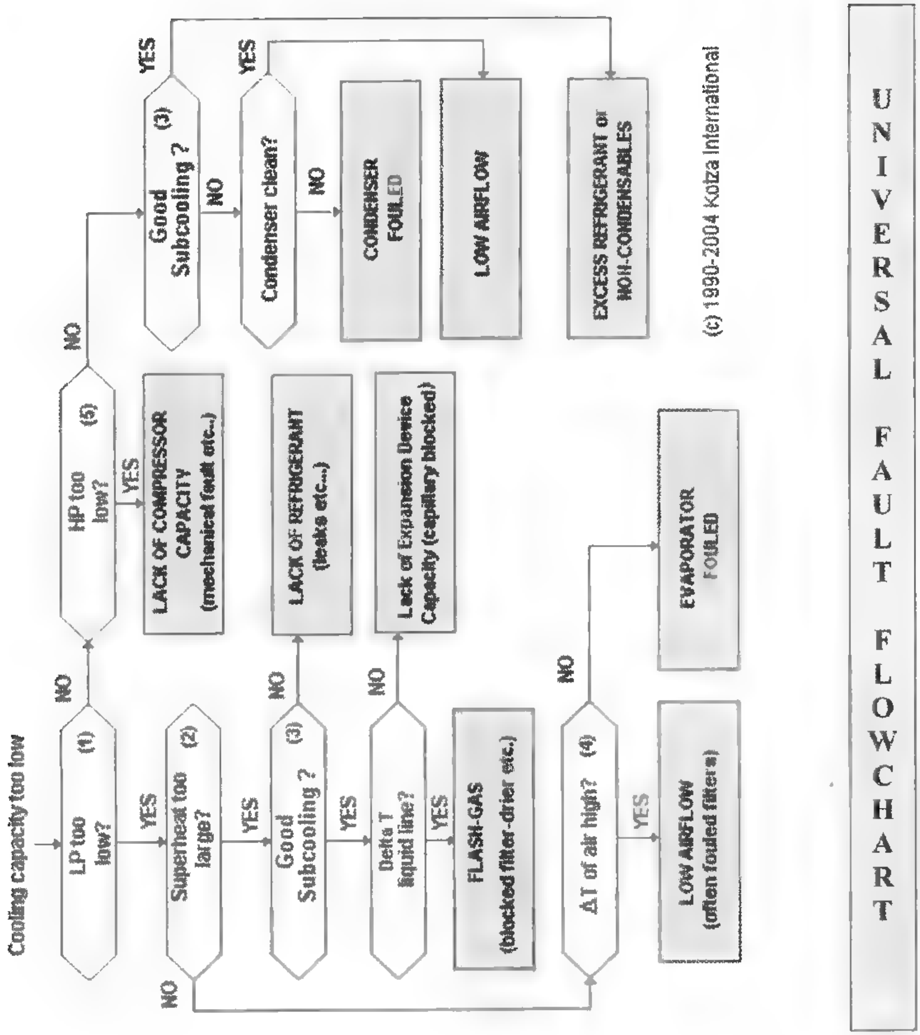
*If liquid slugging has broken a valve, or damaged a moving plate, it won't be sufficient just to replace the compressor. If the source of the liquid hammer is not identified and cured, the same thing will happen to the new replacement compressor sooner or later!*

# REVIEW OF THE PRINCIPAL REFRIGERATION FAULTS

Try and identify the faults in every grey zone in the flow-chart below, using the logical processes we've been studying.




*Solution on next page…*




(1) ΔT total at the evaporator is usually between 16 to 20°C (see page 156). An LP of 8°C is therefore correct with air at 26°C (ΔT total = 18°C), but too small if the air is at 30°C (ΔT total = 22°C) and too large if the air is at 20°C (ΔT total = 12°C).

(2) With a capillary expansion device, the superheat can be variable. However, it should be somewhere between 5 and 10°C.

(3) *In the majority of equipment*, sub-cooling should be somewhere between 4 and 7°C.

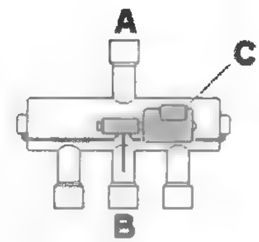
(4) *At high fan speeds,* ΔT of the air at the evaporator is generally of the order of 8 to 10°C.

(5) ΔT total at the condenser can be anywhere between 10 and 20°C, but is most commonly about 15°C (see page 135). A HP of 45°C is therefore correct with air at 30°C (ΔT total = 15°C), too small if the air is at 36°C (ΔT total = 9°C) and too large if the air is at 20°C (ΔT total = 25°C).

# THE REVERSIBLE A/C SYSTEM

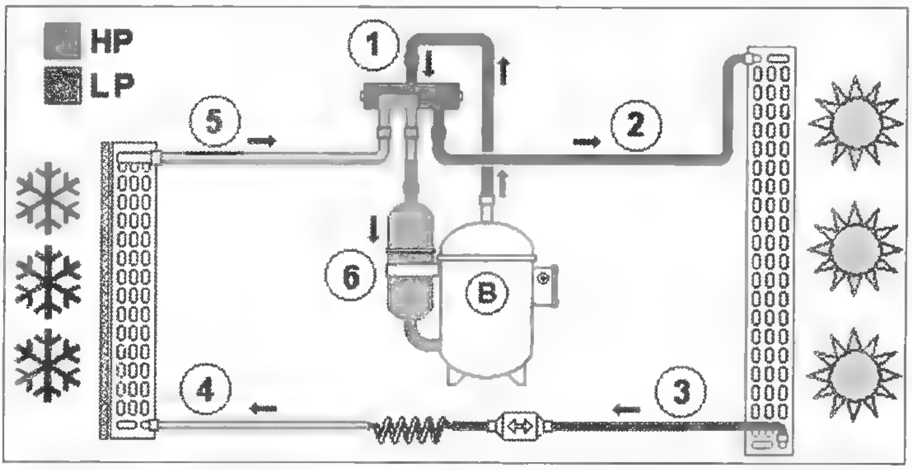
A reversible A/C system performs normal air- conditioning of an area in summer. In addition to this, however, it is also designed to reverse the refrigeration cycle in winter to supply heat to the same area.

The reversal of the refrigeration cycle is brought about by means of a specially designed 4-way valve **(4WV).** At this stage you should be aware that the compressor output is always connected to port **A** (on the side with only a single machined port), and suction to port **B** (the centre one of the three machined ports on the other side). The valve is activated by means of a small solenoid valve (fig **C**).




In order to properly understand how it operates in general terms, let's look at the connection of the 4WV, and the direction of the refrigerant flow in the two cases shown.

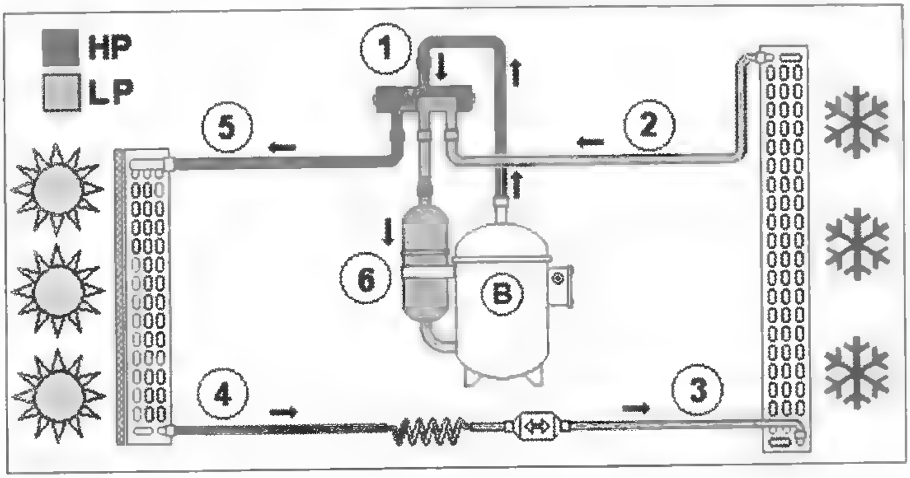
## *"Summer" operation*




The compressor discharges superheated vapour into port **1** of the 4WV. The refrigerant emerges from the valve (by the bottom right port) and is carried by the discharge pipework **2** towards the heat exchanger of the external unit (which now acts as a condenser). The sub-cooled liquid emerges at **3** and then passes through the filter drier and the expansion device. The expanded liquid then enters the heat exchanger of the internal unit (which is now acting as an evaporator) through pipe **4**. The vapour produced is then drawn in through pipe **5** and directed by the slide valve of the 4WV towards the suction line accumulator vessel **6** and then towards the intake of the compressor **B.**

In this position of the 4WV, the heat absorbed on the interior of the area is discharged to the exterior by the condenser: *This is the classical mode of operation for all air conditioning in summer.*

## "Winter" operation




The compressor still discharges superheated vapour into port **1** of the 4WV.

*However, the solenoid has caused the internal slide valve of the 4WV to switch over to the right.*

Refrigerant now emerges from the 4WV (from the bottom left hand port) and is led by the discharge pipework **5** towards the heat exchanger of the internal unit (which now acts as a condenser). The sub-cooled liquid then emerges in **4** and then passes through the bi-directional filter (we will discuss this again on page 252). The expanded liquid enters the heat exchanger of the external unit (which now acts as an evaporator) through tube **3**. The vapour is then drawn through tube 2 and directed by the slide-valve of the 4WV towards the suction line accumulator **6** then to the suction side of the compressor **B**.

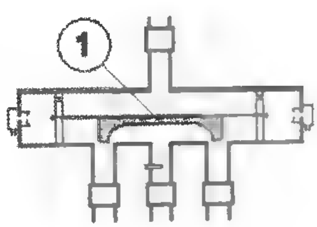
***Note that the condenser has become an evaporator, and vice versa.***

In this position of the 4WV, heat is absorbed from the exterior, and discharged into the internal area. In this reverse cycle operation the system is also known as a heat pump.

## Some faults associated with 4 way valves:

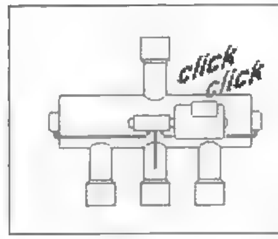
The most difficult fault that can occur with a four way valve is probably the slide valve sticking in a intermediate position (fig 1).

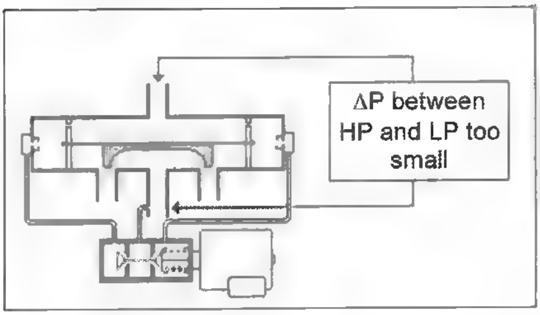
When this occurs, the four pathways are all connected which causes a short circuit between the HP and LP regions, according to the position of the slide valve at the instant it becomes stuck. The system then exhibits all the symptoms of a lack of compressor capacity: reduced cooling capacity, a low HP and high LP (see: lack of compressor capacity, page 242).



There are many possible causes for a sticking slide valve.

Firstly, you need to understand that if the four-way valve is not exposed to HP and LP pressure, and you then supply the solenoid valve with power, you will hear a distinct "click". This does not mean, however, that the internal slide inside the main valve body is moving.

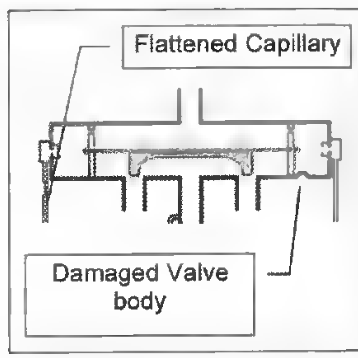


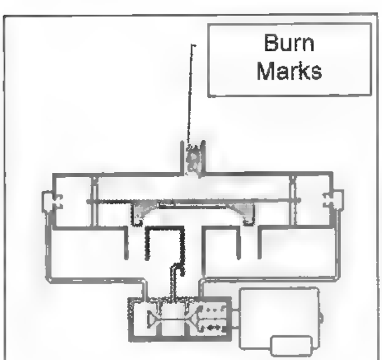

It's actually the pressure difference between the HP and the LP that causes the slide to operate. It's pointless, therefore, to try and operate the slide valve if the compressor is stopped, or if the pressure difference between LP and HP is too small (the minimum ΔP here should be around 1 bar or so).

So, if the solenoid is operated when ΔP is too low, the internal slide will not be displaced to its fullest extent, and there is a possibility that it will stick in an intermediate position.

Another fault that might cause the slide valve to become stuck occurs when the valve body has been damaged as the result of a blow, and is no longer absolutely cylindrical, which prevents free movement of the slide.

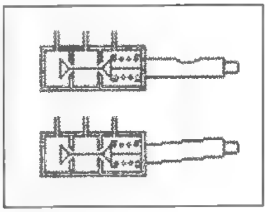



The control solenoid has three small capillaries. If one of them becomes blocked or deformed, the required pressure changes inside the valve won't occur, and the slide valve will stick.




Excessive burn marks on the valve body, and brazing with a poor appearance provide a good indication of the competence of the individual using the blowlamp during assembly. It is essential that the valve body is protected with wet rags or specially formulated paste at the time of brazing. The pistons and the slide valve are surrounded by a gas –tight Teflon seal that eases the movement of the internal assembly of the valve, and this must be protected.

If the temperature of the Teflon exceeds 100°C or so during brazing, it loses its useful characteristics and is irreversibly damaged.

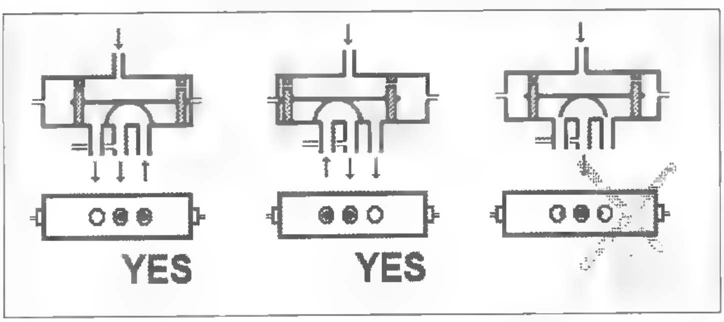


A sticking slide can also be caused by some sort of malfunction of the solenoid, for example by insufficient voltage being supplied, or by poor mechanical assembly of the coil.

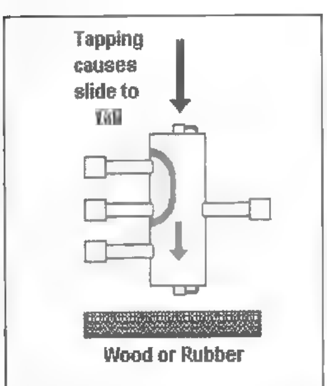
Note that a crushed (following a blow) guide-way or a deformed spindle (due to dismantling or a fall) will prevent the core from moving freely, and that this can also cause a valve to seize.

Remember that a refrigeration circuit should always be spotlessly clean. If copper turnings, pieces of brazing material or abrasives are unwelcome in an orthodox refrigeration system, then there is an even greater risk of them jamming the slide valve or blocking an orifice or capillary in a four-way valve. *Think things out carefully, and take maximum care when you are to work on such a system.*

A slide valve can sometimes even jam because of a feature of the valves' design. *Because the slide can change position freely inside the valve, it can move and find itself in an intermediate position instead of being properly located. This can occur following a blow or exposure to vibration* (in transport for example).




**If the 4WV has not yet been installed,** and there is a chance to examine it, the installer should **ALWAYS** check the position of the slide by looking inside the valve through the three smaller ports. The position of the slide is easily checked in this way.



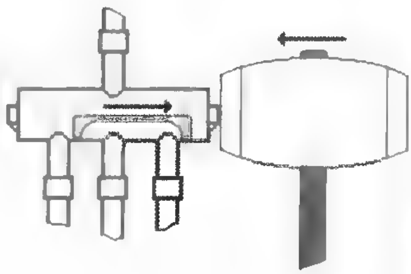

**Remember, once a valve is brazed in place, then it's too late to look inside it!**

If the slide is incorrectly positioned (see the example on the right above), It is possible to bring it to the required position by tapping the end of the valve against a plank or a piece of rubber.

*Never strike the valve against a metallic body, as this could dent the end of the valve and cause it serious damage.*

If the 4WV of a piece of equipment in service is jammed, before thinking about how to replace it, you can always try to free it in place by tapping it (lightly but sharply) *on the desired end* with a mallet. Never use a hammer without first placing a block of wood on the valve, otherwise you could seriously damage it.

A light blow will move the slide



In the example alongside, a tap of the mallet to the right causes the movement of the slide to the right (unfortunately, manufacturers don't always leave enough space around the valve!)

Finally, it is strongly recommended that four way valves are mounted horizontally in order to avoid the slide falling, even slightly, as a result of its own weight.

Before becoming involved in the operation of a four-way valve, a repair engineer should first of all assure himself that there is no refrigeration fault involved. For example, a significant lack of refrigerant charge, causing a severe drop in HP and LP can result in a $\Delta P$ low enough not to allow free and easy movement of the slide valve.

Now we'll consider the solenoid winding. Some inexperienced engineers may be unsure how to determine whether it is working or not. A voltage measured across the terminals of a solenoid doesn't necessarily mean that the coil is energised; it may have a broken wire.

Some engineers place a screwdriver blade on the locating nut of the winding to test the strength of the magnet, but there may not be one in all cases. Others apply voltage to the casing to make the winding move, and listen for the characteristic noise of the core 'jumping'. Yet others remove the winding, and insert a screwdriver to see if it's 'drawn in'. Remember that when you remove an energised winding from its casing it can take about 4 times its normal current, and it could rapidly burn out.

Without removing the winding, a good method of discovering if it is receiving current is to move a clamp-on ammeter which is being held wide 'open' close to the winding.

This will then act as a detector for magnetic fields.

Clamp-on Ammeter fully "open"

If there is a supply to the winding, the ammeter will show a reading.

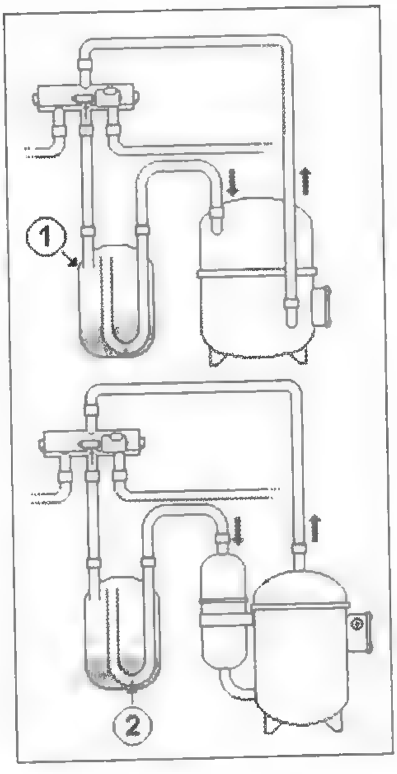
If there is a supply to the winding, the clamp-on ammeter is affected by the magnetic field of the winding, and the ammeter will give quite a high current reading (the value of this reading is irrelevant). This simple procedure provides a sure and rapid way of knowing whether the electro-magnet is operating correctly from an electrical point of view.

Note that the above technique using the "open" clamp-on ammeter is useful for all types of windings fed by alternating current (e.g. solenoids, transformers, motors etc.) as long as the winding is not close to another source of magnetic fields.

The detailed operation and study of multiple faults of the 4WV is outside the scope of this introductory manual. We can only touch on these topics. *If this subject interests you, you will find it useful to consult the REFREPAIR MANUAL (by the same author) pages 325 to 338.*

## The liquid receiver:

In "summer" operation, the condenser is full of liquid refrigerant. Therefore when the cycle is reversed, we've seen the condenser being rapidly transformed into an evaporator. This means that a large quantity of liquid is being drawn towards the compressor. Whatever its design may be, there is then a high risk of compressor damage




In order to avoid such risks, suction line accumulators or receivers are generally installed on the suction side of reciprocating compressors. (Figure 1)

Rotary compressors are already equipped with such items of equipment. However, in air conditioning systems where the cooling capacity exceeds about 5 kW, the amount of liquid refrigerant liable to return to the compressor after a cycle reversal can be greatly superior to the capacity of the receiver already installed. Manufacturers then introduce a second receiver. (diagram alongside).

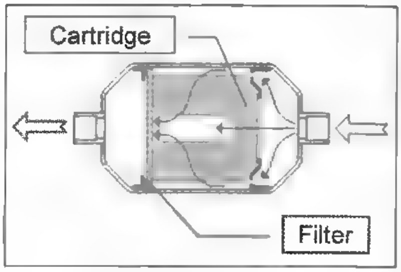
The receivers are designed to ensure that any possible inrush of liquid will not reach the compressor, particularly after the reversal of a cycle. The liquid then remains trapped in the bottom of the receiver. Since the suction to the compressor is taken from the top of the receiver, the compressor can only ever draw in vapour, which totally eliminates the possibility of liquid hammer occurring.

We've seen that oil is carried around the entire system by the refrigerant. In order to prevent the oil becoming trapped at the bottom of the receiver, a calibrated orifice (fig 2 previous page) is provided in the bottom part of the suction U-tube

In this way, when liquid (oil or refrigerant) is present in the bottom of the receiver, it is gradually drawn through the orifice and can therefore return to the compressor without risk of liquid "slugging".

## The bi-directional filter drier:

According to the operating mode (summer or winter), refrigerant may flow through the liquid line in both directions (see diagrams on pages 246-247).

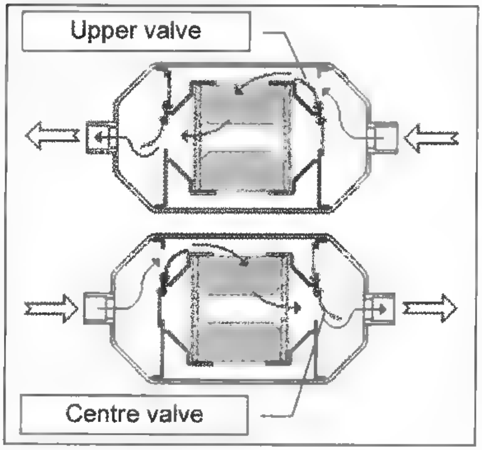



Since the capillary is a simple calibrated tube copper, there is no restriction on the direction of flow. This is not the case with the orthodox filter drier shown alongside.

This filter is fitted with a solid cartridge that absorbs water and retains gross pieces of contamination. A very fine filter is then placed at the outlet to trap any small particles.

Note that the filter drier of an air conditioning system of 2kW refrigerating capacity can only absorb 50 to 100 milligrams of water, that's the equivalent of one or two droplets: *It cannot be said too often that extreme vigilance needs to be used in order to prevent the entry of any moisture into the system.*

If you fit this type of filter drier into a reversible air conditioning system, all the impurities retained by the cartridge will be swiftly released into the circuit as soon as the cycle is reversed.




This is why bi-directional filter-driers are used which are fitted with two filters and two valves.

In whichever direction flow is taking place, the refrigerant always enters the cartridge after passing through the top valve, crosses the filter, and then leaves via the centre valve.

In this way, impurities are forced to remain trapped between the upper valves and the filters, whichever direction the flow is in.

***So never replace a bi-directional filter-drier with a single flow direction model!***

# SINGLE PHASE MOTORS

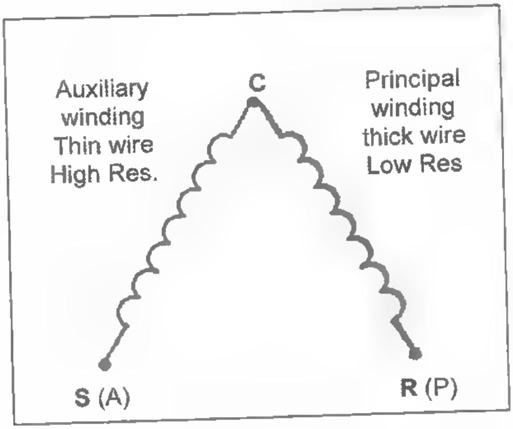
It is rare to find a comfort air- conditioning system that isn't equipped with one or more single-phase motors. Despite being so widespread, this type of motor is frequently less well understood than its three-phase equivalent.

The aim of this chapter is not to study how or why these motors operate, but to gain an understanding of their electrical connections, their repair, and their accessories (capacitors and start-up relays). Naturally, we will concentrate particularly on compressor motors.

## Single phase motors: general points:

Motors for small compressors or fans supplied with single phase 220V are fitted with two coils or windings:

- The **R**unning (**R**) sometimes called the **P**rincipal (**P**) coil is made up of a larger diameter wire. This winding is designed to be continually under voltage, and to carry the nominal current for the motor.
- The **S**tart (**S**) also called the **A**uxiliary (**A**) coil is made from a thinner wire. This means that it generally has a higher resistance in most applications, which enables it to be easily identified.



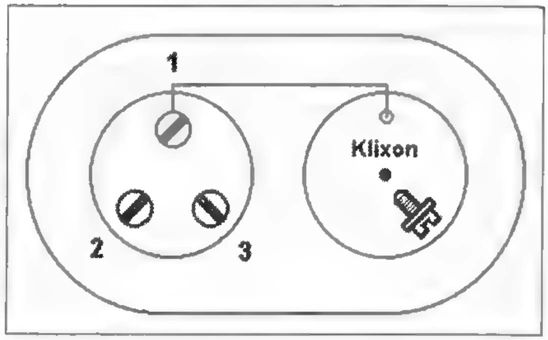

As its name indicates, the auxiliary "start-up" winding is intended to help the motor start running.

If voltage is applied to the principal winding of a motor (without applying it to the auxiliary winding) the motor "rumbles" and is unable to start. If it is then spun by hand, it will start to turn and continue to rotate *in the direction in which it was spun*. This is what happens when an opposing wind starts to turn the blades of a condenser fan in the wrong direction (see: lack of condenser capacity p235.)

The auxiliary winding is designed to optimise the start-up of the motor, by providing a starting torque greater than the torque due to the resistance of the machine being operated. Normally air conditioning systems are fitted with a device that prevents short cycles. It allows sufficient time for the HP and LP pressures to equalise through the capillary before the compressor will start. The starting torque is then minimised.

*It is strongly recommended that the compressor never be started before this equalisation has occurred. If it is, then "stalling" could occur and the motor will then cutout because of the safety devices fitted.*

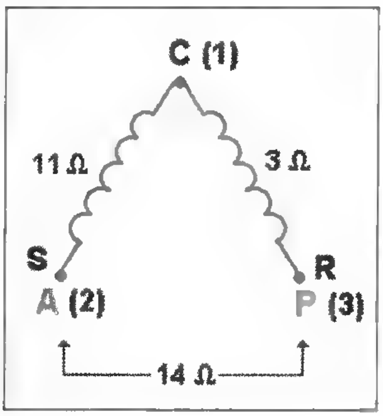
Let's examine the terminal box of the single-phase hermetic compressor below. The "klixon" circuit breaker protecting the compressor against accidental overheating can be seen, and the three motor terminals are indicated as 1, 2 and 3.




**If all wires are disconnected,** an ohmmeter will show, for example, the following readings:

Between 1 and 2 ⇔ 11 Ω
Between 1 and 3 ⇔ 3 Ω
Between 3 and 2 ⇔ 14 Ω

*Note: use a low range (e.g.* 200 Ω) as the resistances in these small motors are at most only a few tens of Ohms.




This suggests an internal arrangement as shown below:

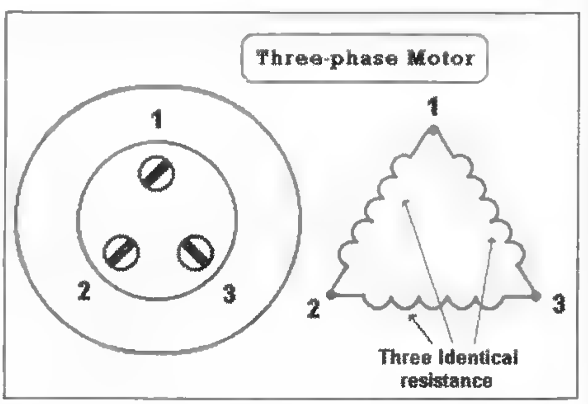
- The largest resistance is found between (2) and (3). The other terminal (1) then is Common **C**.
- The smallest resistance is found between (1) and (3). This, then, is the **Run (R)** winding.
- Therefore the **Start (S)** winding is connected between (1) and (2).

**Warning:** these measurements must be taken with the greatest care, especially if the motor is a model that is unfamiliar, or whose connection diagram is unavailable.

**An accidental confusion between the principle phase and the auxiliary phase generally ends up as a motor burnout soon after you apply a voltage to the motor!**

**NOTE:**

With a three-phase motor, the meter would give three identical readings between the three terminals. It would seem to be difficult to go wrong in testing this type of motor.




*In all instances, make a habit of reading the specification plates of the motors. Also remember to look **inside** the terminal box cover. **The connection diagram for a motor can often be found there!***

## How do you electrically test a motor?

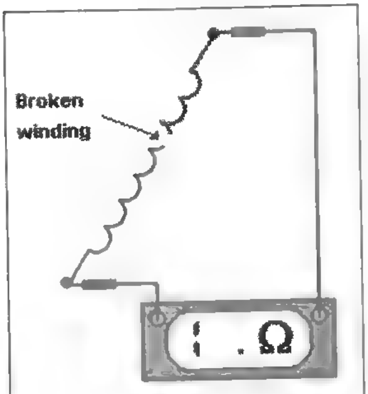
If there is a particularly difficult decision for an inexperienced engineer to take, it is how to diagnose a "burned-out" motor. So let's remind ourselves about the electrical faults that may arise, whether we're concerned with a single-phase or three-phase motor.

Most of these faults are caused by overheating of the motor, which is frequently due to excessively high current being passed. This excessive current could be electrical in origin (increased voltage drop, over-voltage, incorrect settings on safety devices, poorly made electrical connections, defective contacters etc.), due to refrigeration (high HP, acidity in the system etc.) or mechanical in origin (seizing due to a lack of oil etc.).

***One of the windings is broken.***

When this occurs, an Ohmmeter across the terminals of the windings shows a very high resistance instead of the normal sort of value for a winding. Make sure that the meter is operating correctly, and that its leads are making proper contact with the motor terminals. Use the meter on a high resistance range.

Remember that a standard small motor winding has a maximum resistance of *tens* of Ohms, and the windings of the largest motor, a *few tenths* of an Ohm. If a winding is broken, hermetic compressors must be replaced.



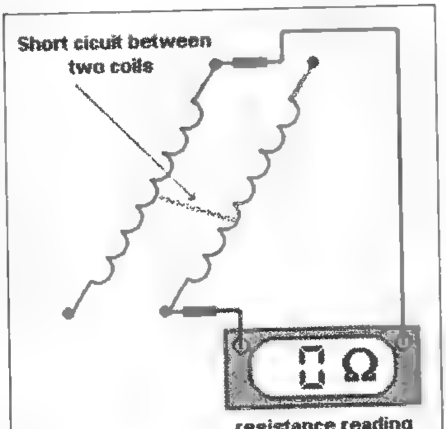
Resistance measured tends to infinity

***There is a short-circuit between two windings.***

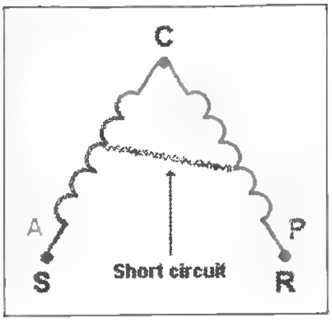
To carry out this test, the motor wiring must be removed (as well as the coupling bars on three-phase motors).

**When you disconnect any wiring, always make a detailed diagram, and use as many markers as you can. This will allow you to perform trouble free re-connection later.**

In the example opposite, the Ohmmeter on a high range should show an infinite resistance (there should be no connection between the two windings). As it is reading 0 Ω (or a very small resistance value) a short-circuit between the two windings is indicated. If there is a short circuit between windings, the hermetic compressor must be replaced.



resistance reading tends towards zero



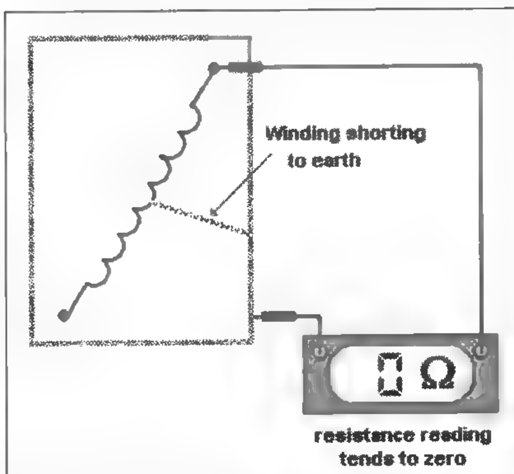

The diagnosis is less obvious with a single-phase motor with an auxiliary winding, as the two windings cannot be disconnected (the common C connection is made inside the motor)

Depending on the exact location of the short circuit, the three measurements made between the three terminals (C⇔S, C⇔R and R⇔S) *give somewhat reduced values which are quite non-conclusive*. For example, the resistance measured between S and R may not correspond to the sum of the resistances C⇔S + C⇔R.

As with a broken winding, a short circuit between windings means that the compressor must be replaced.

***A winding is shorting to earth.***

The insulation resistance of a new motor (between each winding and earth) can approach 1000 MΩ. With age, this resistance drops, and can fall to 10 to 100 MΩ. It is generally considered that from 1000 kΩ (1 MΩ) one should plan to replace the motor, and that below 500 kΩ, *the motor is no longer serviceable* (reminder: 1 MΩ = 1000 kΩ = 1000000 Ω).



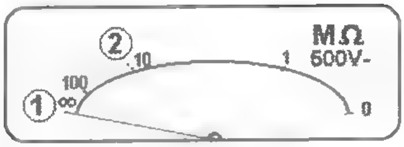

If there is an open earth, an Ohmmeter connected between one of the motor terminals and the metal body of the motor would show 0 Ω (or a very small resistance) *instead of infinity*.

Note that this measurement should be made *on each of the motor terminals* using the highest meter range.

Before each measurement is made, check that the meter is functioning correctly, and that the leads are making proper contact with the terminals and the motor body. Scrape off any paint to ensure a good contact, and never touch the leads with your fingers as this could significantly affect the readings!

In the example above, the measurement shows that without a doubt the winding in question is open to earth.

However, the earthing of the winding may only be partial. The insulation resistance between the winding and the body may appear to be adequate with a standard Ohmmeter when the motor is cold. On the other hand, when voltage is applied and it starts to become warm, the insulation may decrease sufficiently to cause the differential circuit breaker to trip out.




A Megger insulation tester (or its equivalent) should therefore be used to test insulation resistances at a continuous potential of 500V, instead of the few volts of a standard Ohmmeter.

When the instrument's handle is turned, if the insulation resistance is correct, the needle moves to the left (see **1**) and reads infinity ($\alpha$). A smaller reading, of 10 MΩ for example (see **2**) indicates defective insulation of the motor. Whilst this may be insufficient to cause the differential cut-out to trip by itself, it should be noted and reported, as the sum of a series of small insulation defects will sooner or later cause a total breakdown of the installation.

*To summarise, then: Testing of suspect electrical motors requires a good deal of care.* In every case, it is not sufficient just to replace the motor. The source of the fault (whether electrical, mechanical or refrigeration) should be investigated thoroughly, so that there is no possibility of it recurring.

In the case of a refrigeration compressor, there is a strong possibility that there is acid present after a compressor "burnout" (this can be detected by a simple oil analysis).

This means that even more care needs to be taken. Above all, electrical problems need to be considered (possible replacement of circuit breakers, testing of connections, testing of safety cut-outs etc.)

## Start-up and Operating Capacitors:

In order to start-up a single-phase motor with an auxiliary winding, a starting impulse must be generated, Usually a capacitor (sometimes confusingly called a condenser) is connected in series with the auxiliary winding in order to provide an impulse corresponding to the required starting torque.

If the capacitor is wrongly sized (too large or too small) the impulse obtained may not be sufficient to enable correct start-up of the motor. It could then stall and the security circuit could trip-out.

**In Comfort A/C systems we might encounter 2 types of capacitors:**

- ***Operating (or Run) capacitors*** (paper) provide a small capacitance (rarely more than a thirtieth of a μF) and have large dimensions. The are designed to be continually under voltage without becoming excessively hot.
- ***Start-up capacitors*** (electrolytic) on the other hand possess a large capacitance (possibly more then 100 μF) despite being rather small. They must never have a continual voltage applied, as they will quickly overheat and may explode. The maximum time that voltage can be applied is about 5 seconds, and 20 start-ups an hour represents the most that they are able to tolerate.

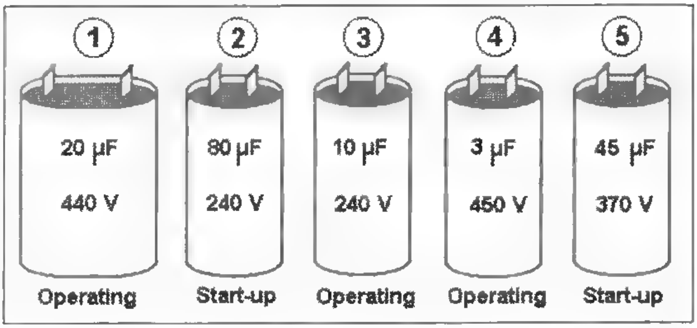
The geometry and dimensions of a capacitor depend on:

- *Its capacitance value* (the larger the capacitance, the bigger the capacitor). The capacitance is indicated in microfarads (μF or uF or MF or MFD according to the manufacturer) with the manufacturing tolerances. For example: 15 MF±10% (the capacitance is between 13.5 and 16.5 μF) or perhaps 88-108 MFD (the capacitance is between 88 and 108 μF).

- *The voltage value* indicated on the capacitor (the larger the voltage value, the larger the capacitor).
  It is useful to remember that the voltage shown refers to the *maximum voltage* that the capacitor can tolerate across its terminals without deterioration resulting or excessive heat being produced. So if it is marked 20 μF / 360 V, the capacitor can be used without problem at a voltage of 220 V, but should never be connected to a 380 V circuit.

### *How do we recognise the capacitor type?*

Let's examine the capacitors opposite.




No.1 is much larger than the other 4, with a rather small capacitance considering its size. From this evidence it is an operating (or Run) capacitor.

Capacitors 3 and 4 have a small capacitance. Note that no.4, whilst designed to be used at a higher voltage than no.3, has a smaller capacitance. These are both operating (or Run) capacitors.

Capacitor no.2 has a large capacitance for its size, and is a start-up capacitor. Capacitor no.5 has a somewhat smaller capacitance than no.2, but it will tolerate a higher voltage; it is also a start-up capacitor.

*Remember that although an operating (or Run) capacitor can be supplied with a continual voltage, a start-up capacitor shouldn't have voltage applied to it for more than 5 seconds. In addition, it should never be subjected to more than 20 start-ups an hour.*

At this point, before we look in more detail at how to test a suspect capacitor, it may be useful to remind ourselves what happens when a meter is connected to its terminals.

*Fig.1:* The capacitor plates being completely discharged, the voltage **U1** across its terminals is of course zero. As soon as the Ohmmeter is connected, the needle soon moves towards 0, which proves that a significant current **I1** passes between the plates of the condenser.

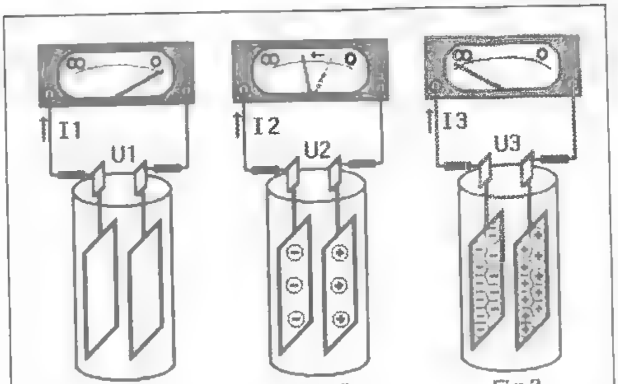


Fig.1 Fig.2 Fig.3

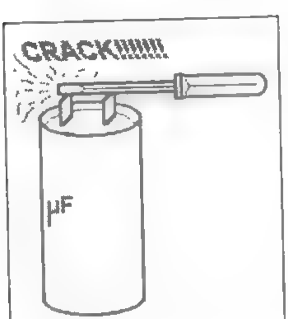
*Fig.2:* The needle is then observed to return slowly towards the left, indicating that the current **I2** passing between the plates is smaller than the earlier current **I1.** Simultaneously the voltage **U2** between the terminals of the condenser increases slowly.

*Fig.3:* The meter needle is at infinity (∝), which indicates that the current **I3** is zero and that no current is passing between the plates of the capacitor. The voltage **U3** across the terminals is therefore equal to the voltage of the meter's battery.

This progressive reduction in the current is explained by the fact that the capacitor's plates gradually become charged. This results in the increase in the voltage between the plates. The difference between the voltage at the capacitor terminals and the voltage of the meter battery diminishes. *When this difference becomes zero, the current becomes zero (fig.3) Conversely, when this difference is greatest, the current is at a maximum (fig.1).*

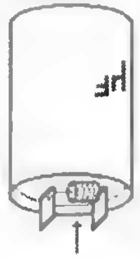
In our example, when the capacitor is completely charged the voltage across its terminals equals the voltage of the ohmmeter battery (a few volts), and when the meter is disconnected, the plates remain charged. When the capacitor has been connected to a 220V circuit, *this means that there could be 220V between its terminals even when disconnected!*

**WARNING! DANGER:** In this case, if you place your fingers on the terminals of the capacitor, you'll receive an electric shock just as if you'd put your fingers into an electric point for a brief moment.



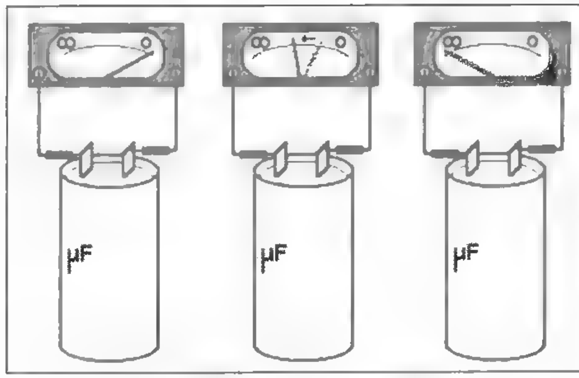

In the same way, connecting a meter to a charged capacitor *is equivalent to plugging it into an electric point.* Your only hope would be that the instrument's fuse works correctly and in time.

**It is essential therefore, *before doing any work on a capacitor*, to disconnect it and reassure yourself that it is completely discharged. This can be done, for example, by shorting it out with a screwdriver with insulated handle (take care as the spark produced can be intense).**




Some capacitors are fitted with a discharge resistance connected between their terminals. This resistance is high enough (about15 kΩ) not to affect the performance of the capacitor, but will still allow the capacitor to discharge slowly when voltage ceases to be applied.

Even if the capacitor is fitted with a discharge resistance, *always take the precaution of short-circuiting a capacitor before working on it* nonetheless. Complete discharge of a capacitor isn't instantaneous when voltage is removed, and may take several minutes.




Before looking at various faults in capacitors, let's remind ourselves that when we connect a meter to the terminals of a capacitor in full working order (after disconnecting and discharging it) the needle should rapidly move towards zero and then return slowly towards ∝. If the leads of the meter (and hence the polarity) are interchanged the same phenomenon takes place.

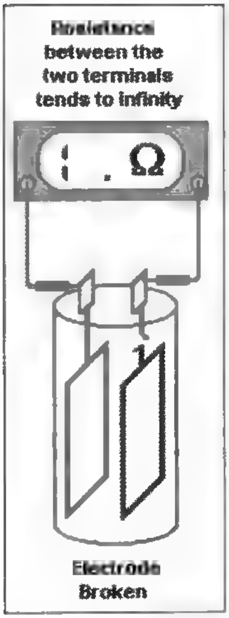
With digital meters in common use nowadays, the effect is less visible. However, the display's tendency to increase towards +∝ can be plainly observed. When the polarities are interchanged, the display shows -∝ and then rises towards 0 and then to +∝ (these changes occur more slowly for small range settings, so use the 20 kΩ or 200 kΩ ranges).

***If you think that you need some practice, try the above with new capacitors, and carefully observe what happens. This will enable you to proceed with confidence during a repair.***

## How do we test Capacitors?

Ohmmeter readings, when they give the results that we've just seen are an excellent indication of the "health" of a capacitor. Nevertheless, these readings should be complemented by measurements of the actual capacitance value of such a component, and we'll examine the methods for doing this shortly.

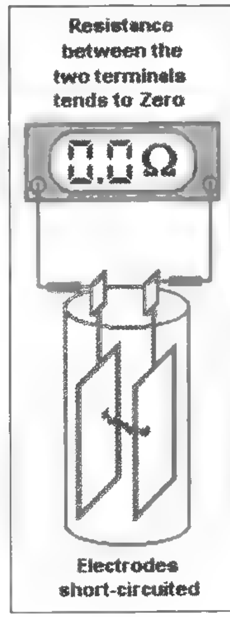
Now we'll examine the various defects associated with capacitors, such as short circuit, broken circuits, earthing, capacitance loss etc., and how we diagnose them. **From now on, remember that a swollen capacitor cover is completely abnormal.**




**← There is a break in the capacitor circuit.**

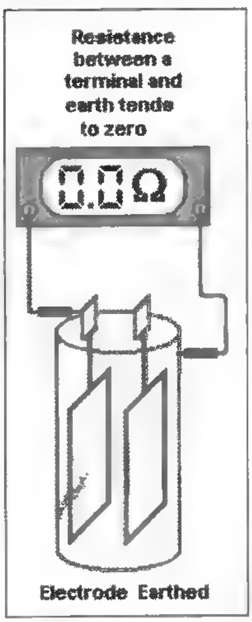
When this occurs, an Ohmmeter set to a high range will continuously read infinity when connected across the terminals.

With this fault, everything behaves as if there were no capacitor in the circuit. Now, a capacitor is fitted for a reason, and so we can predict that the motor wouldn't operate normally, or it couldn't be started. This would usually cause the safety cutouts (klixon) to trip.



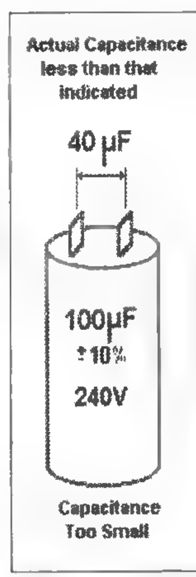

**The capacitor has short-circuited. →**

With this fault, a meter (set to a low range) placed across the terminals will permanently read 0 or a very low resistance. In some cases the compressor can start, but in most instances a capacitor short- circuit would lead to a thermal cutout tripping.




**← The capacitor is earthing.**

As with electric motor windings, capacitor electrodes should always be insulated from earth. If the insulation resistance falls significantly, (which generally occurs as a result of overheating) the current leaking to earth will cause the installation to stop through tripping the differential circuit- breaker. This particular fault usually occurs when the capacitor has a metallic casing. When it does occur, the resistance measured between a terminal and the motor body tends to zero, instead of showing ∝. Ensure that both terminals are tested for this fault.



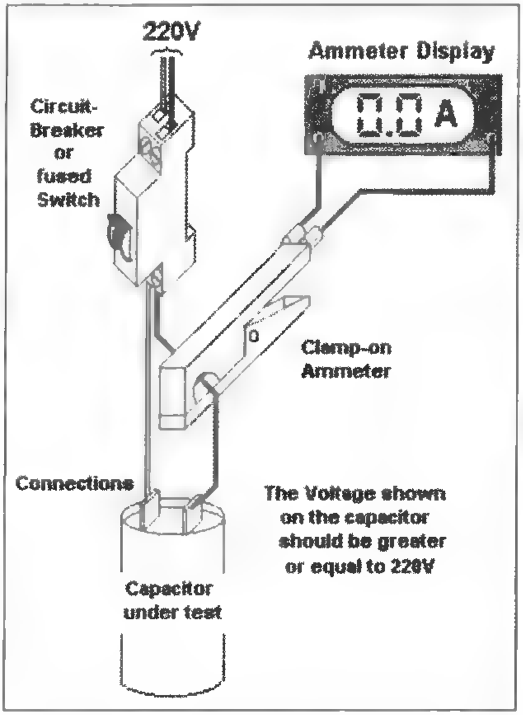

**The actual capacitance is too small →**

In this instance the true value of the capacitance measured across the terminals of the capacitor is smaller than the values indicated, if the manufacturing tolerances are taken into account.

In the example opposite, the measured capacitance should be between 90 and 110 µF. The capacitance is actually too small, and cannot supply the required impulse and starting torque. There is a strong possibility that the motor will not start and that the safety devices will trip out.

Let's look now at how to measure the actual capacitance of a capacitor, using an arrangement that is relatively easy to set up on site.

**WARNING! In order to avoid accidents, it is essential to test the capacitor using an Ohmmeter before setting up this test arrangement.**



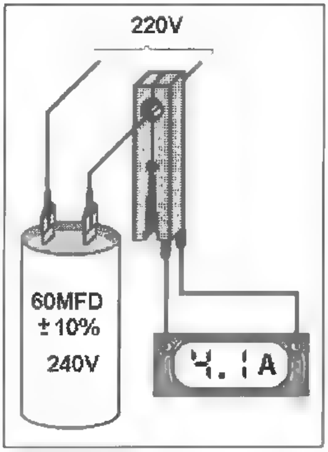

Since the capacitor appears to be in good condition, all that we need to do is connect it to a 220V circuit and measure the current that is flowing. Of course, the voltage shown on the capacitor must be at least 220V.

It is *essential* that the arrangement be protected either by a circuit breaker or a fused switch. The measurement should take as short a time as possible as it may be dangerous to apply a continuous voltage to a start-up capacitor.

**With a 220 V supply, the actual capacitance of the capacitor (in μF) is about 14 times the measured current (in A).**

For example we might need to test the actual capacitance of the capacitor below, (since it's obviously a starting capacitor, the time during which voltage is applied should be as short as possible). Since it's marked 240V, it can be connected into a 220V circuit.

Since its stated capacitance is 60 μF ±10% (between 54 and 66 μF), it should theoretically carry about: 60 / 14 = 4.3 A.




A fused switch or a circuit breaker capable of carrying this current is incorporated in the circuit. The clamp-on ammeter is placed in position and set to the 10 A range, for example.

The capacitor then has voltage applied to it, the current is read off the ammeter, and then the voltage is switched *off as soon as possible*.

**WARNING! DANGER: When you measure the capacitance of a starting capacitor, voltage should be applied for no more than 5 seconds** (experience indicates that this length of time is usually sufficient for taking the reading; all that is needed is a bit of organisation!)

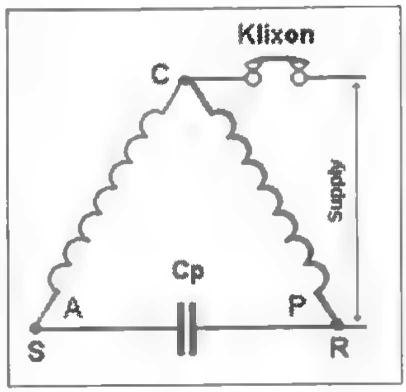
In our example, the true capacitance is about 4.1 x 14 = 57 µF. The capacitor is therefore OK, as its capacitance should be somewhere between 54 and 66 µF. If the measured current had been, for example, 3 A, the true capacitance would have been 3 x 14 = 42 µF. Since this value is outside tolerance limits, it would have been necessary to replace the capacitor.

## Start-up systems used in Comfort A/C:

In this type of A/C equipment, we essentially come across two start-up systems; one uses a permanent capacitor, and the other a voltage relay.

### Start-up using a permanent capacitor:

This system is the simplest, and also the most widely utilised in comfort A/C systems.



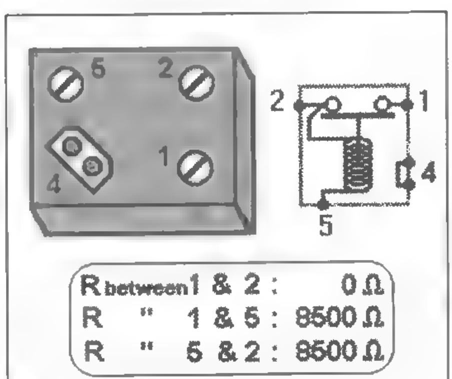

As there is a continuous voltage supplied to the capacitor, it must be an operating (or Run) capacitor. As larger capacitance components of this type are very large, they are generally limited to a fairly low capacitance value (rarely more than 10 µF or so).

This arrangement is widely used in small motors powering equipment with a low opposing torque. These include fans on small A/C units or rotary compressors, with capillary expansion devices enabling pressure equalisation when on stop.

When voltage is applied to this sort of arrangement, the permanent capacitor (Cp) provides a "boost" which enables the motor to start running. Once the motor has started to run, voltage to the auxiliary winding is maintained, which helps provide additional torque to the motor during operation.

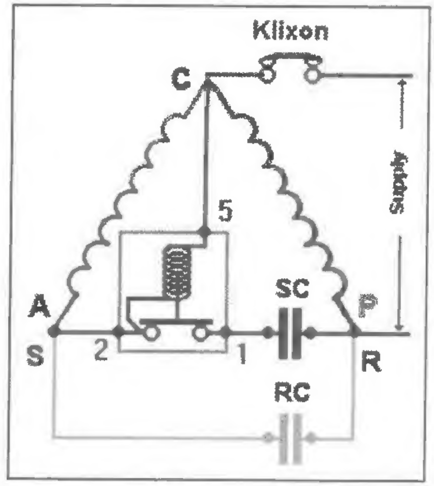
### Using a voltage Relay:

Starting some large single-phase compressors is performed using a voltage relay.




Represented alongside is a widely available voltage relay. It is supplied as a black hermetically sealed box. The power contact is between 1 and 2 (the resistance is 0 Ω) and the actuating (signal) coil between 2 and 5 (this has a resistance of about 8500 Ω). Note that terminal 4 is not connected internally, and is present as an aid for wiring.

Let's examine the operation of the voltage relay represented in the diagram below, and shown in the standby position (i.e. off-line).




As soon as power is supplied, current passes through the "klixon" circuit breaker, and the Run winding (C⇔R). Simultaneously, it passes through the start- up winding (C⇔S), the contact 2-1 (which is closed) and the starting capacitor (SC). All the required conditions for start-up are present and the motor starts to rotate.

As the motor gradually picks up speed, a voltage is induced across the terminals of the auxiliary coil by the rotation of the motor, and this voltage is added to the supplied voltage.

As start-up is nearing completion, with the induced voltage at a maximum, the voltage across the terminals of the auxiliary winding can reach 400 V (with a supply voltage of 220V). The voltage relay coil is designed to operate when the voltage at its terminals exceeds the supply voltage by an amount specified by the manufacturer. When the contact 1-2 opens, the relay coil is still supplied by the induced voltage from the Start winding (this winding, forming a coil underneath the Run winding, behaves just like the secondary winding in a transformer).

The Run capacitor **RC** shown in grey on the diagram is sometimes included to provide the motor with a larger running torque (for example in tropical equipment where the HP may become very high).

There are many models of voltage relays in existence, each with different characteristics e.g. contact closing voltage, contact opening voltage etc. Of course, if it becomes necessary to replace a defective voltage relay, a replacement of exactly the same specification must be used. If the replacement relay isn't perfectly compatible with the motor its contact may open too soon during start-up, or stay permanently closed.

A good professional should be capable of specifying, installing, commissioning and performing any maintenance task on an air conditioning system, in accordance with the regulations. We hope that this work will help you achieve this objective.

In conjunction with studying this manual, using the REFRIBASE SOFTWARE FOR YOUR PC will save you an enormous amount of time in acquiring the necessary knowledge to perform these tasks. *If you don't have any previous experience, we would advise you then to take a short practical course of 2 or 3 days with one of the many specialist organisations.*

**Thank you for your attention, and Happy Air Conditioning!**

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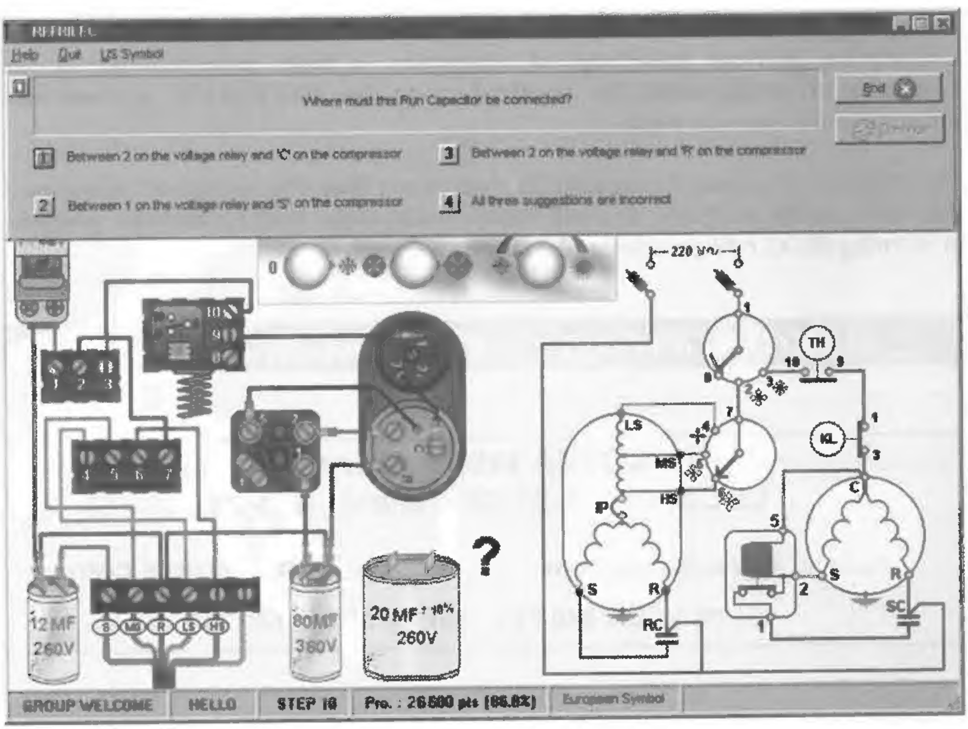

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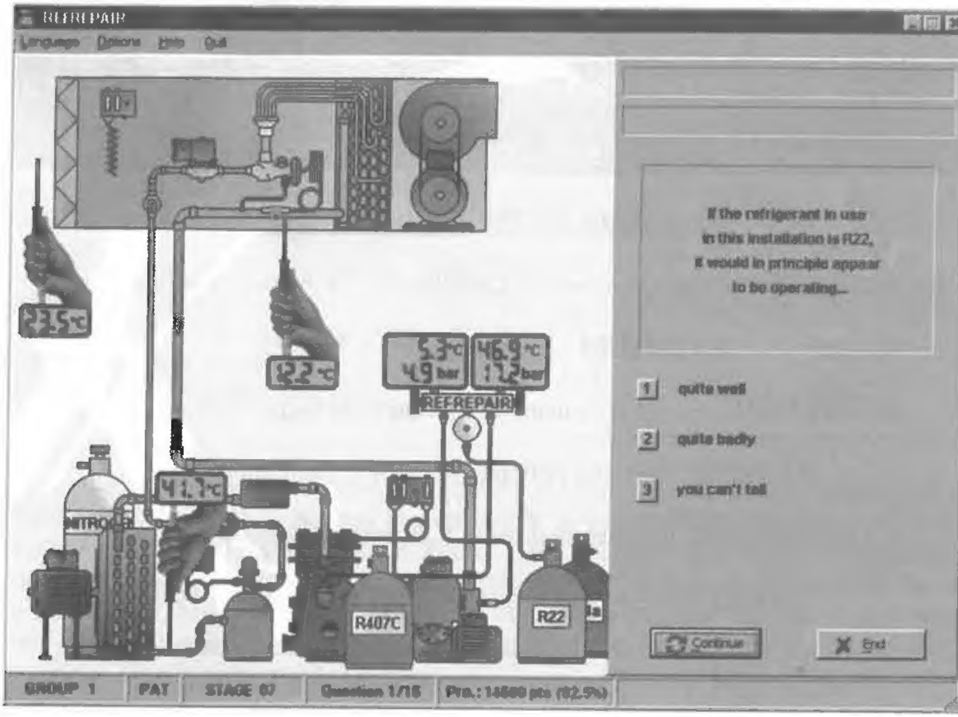


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# PERSONAL NOTES